TERA

Report of the Expert Peer Review of Sulfolane Reference Doses for the Alaska Department of Environmental Conservation

Volume Three - Appendix

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Independent

Non-Profit

Science

For Public Health Protection

Toxicology Excellence for Risk Assessment

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Website Documentation Appendix

- RfDs for Review
  - Canadian Council of Ministers of the Environment (CCME). 2006. "Canadian Environmental Quality Guidelines for Sulfolane: Water and Soil (Scientific Supporting Document)." PN 1368.
    - This document is available from CCME at: http://www.ccme.ca/files/Resources/supporting_scientific_documents/sulfolane_ssd_soil_water_1.1_e.pdf
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  - Haney, J. [Texas Commission on Environmental Quality (TCEQ)]. 2011. Sulfolane (CASRN 126-33-0) [re: Update of March 9, 2011 toxicity factor documentation with a slightly revised benchmark dose (BMD)]. September 6.
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  - Magee, B. (ARCADIS U.S., Inc.). 2012. Memorandum to Flint Hills Resources Alaska re: Assessment of dose response information for sulfolane. May 21.
  - Thompson, CM; Gaylor, DW; Tachovsky, JA; Perry, C; Carakostas, MC; Haws, LC. 2013. "Development of a chronic noncancer oral reference dose and drinking water screening level for sulfolane using benchmark dose modeling." J. Appl. Toxicol. 33(12):1395-1406.
    - This document is available from the publisher at: http://onlinelibrary.wiley.com/doi/10.1002/jat.2799/suppinfo
  - Health Canada. 2014. "Drinking Water Guidance Value for Sulfolane." March 17.

- Submitted Technical Scientific Comments
  - Submitted by Dr. Laurie Haws on 9/08/14
    - ToxStrategies Comments_TERA Sulfolane Peer Review_090814_2_submitted
  - Submiteed by Dr. David Gaylor on 9/08/14
    - Gaylor_Sulfolane_Gradient Report_2_submitted
  - Submitted by Dr. Brian Magee on 9/08/14
    - FHRA_NPR_Revised Final Draft HHRA Posted
    - ARCADIS Memorandum_Response to Gradient Report_20140908
  - Submitted by Dr. William Farland on 9/08/14

        - Farland_Coupling Exposure to the RfD_9814
- Submitted by Chad Thompson on 9/08/14
    - Supplemental materials for the manuscript “Thompson, CM; Gaylor, DW; Tachovsky, JA; Perry, C; Carakostas, MC; Haws, LC. 2013. Development of a chronic noncancer oral reference dose and drinking water screening level for sulfolane using benchmark dose modeling." J. Appl. Toxicol. 33(12):1395-1406” were provided to panel members.
        - This document is available from the publisher at: http://onlinelibrary.wiley.com/doi/10.1002/jat.2799/suppinfo
- Submitted by Dr. William Farland on 8/25/14
    - Sulfolane Hazard Characterization – Considerations, William H. Farland, Ph.D., ATS, April 5, 2012
    - Perspectives on the Journal of Applied Toxicology Article entitled “Development of a chronic non-cancer oral reference dose and drinking water screening level for sulfolane using benchmark dose modeling”, William H. Farland, PhD, ATS, May 30, 2014
- Submitted by Mr. David Smith on 8/26/14
    - Arcadis’ Supplement to the Revised Draft Final Human Health Risk Assessment

Health Consultation

Sulfolane

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Prepared by

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Table of Contents

Introduction and Background

The Alaska Department of Health and Social Services requested that the ATSDR Division of Toxicology and Environmental Medicine provide a chemical specific health consultation for the chemical sulfolane. Sulfolane has been detected in the groundwater under the city of North Pole, Alaska and a completed exposure pathway exists to residents through the groundwater. Alaska specifically requested that ATSDR develop a public health action level for sulfolane in the drinking water, as well as describing potential health effects of sulfolane exposure. The public health action level is a non-regulatory level set to identify if human exposure to that water needs to be evaluated further (a/k/a, a screening level). If exposure is occurring, then consideration should be given to reducing that exposure.

Chemical and Physical Properties of Sulfolane

Sulfolane is an industrial solvent used in liquid-liquid and liquid-vapor extraction of compounds such as aromatic hydrocarbons from petroleum (VKH Brown et al. 1966; Andersen 1976; HSDB 2006). Sulfolane has also been reportedly used in fractionalization of wood tars, a component of hydraulic fluid, textile finishing, and as a curing agent in epoxy resins (HSDB 2006). Sulfolane has reportedly no odor and is completely miscible in water, acetone, glycerol and many oils (VKH Brown et al. 1966). Figure 1 shows sulfolane's molecular structure. Important physical properties are summarized in Table 1. Sulfolane mixes well in water, is not very volatile, not highly viscous and is highly polar.

Figure 1: Sulfolane

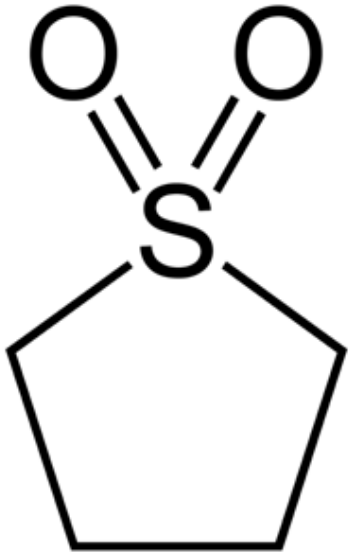

Table 1: Physical Properties of Sulfolane (VKH Brown et al. 1966; HSDB 2006; NIOSH 2006)

Physical Property	Value
CAS Number	126-33-0
Molecular Weight	120.18
Freezing Point	27.4 – 27.8 °C
Boiling Point	285 °C
Specific Gravity (30/20 °C)	1.265
Refractive Index	14.53 mm. Hg
Vapor Pressure (27.6 °C)	0.0062 mm. Hg
(116 °C)	5 mm. Hg
(150 °C)	14.53 mm. Hg
(250 °C)	333.70 mm. Hg
Henry's Law constant	4.6 X 10^{-6} atm-m^3/mole
Viscosity	10.3 Centipoises
Dipole moment (in benzene)	4.69 Debye
Dielectric constant (33 °C)	44

Absorption, Distribution, Metabolism and Excretion

Sulfolane is not well absorbed through human skin, with a reported permeability constant of 0.2 g/m^2/h (Ursin et al. 1995). Sulfolane is well absorbed through the oral route (Andersen 1976). Blood sulfolane decay curves were generated following intravenous injections of sulfolane in rabbits, dogs and squirrel monkeys (Andersen et al. 1977). Sulfolane distributed rapidly in test animals, with a reported volume of distribution that was near 1.0 l/kg (Andersen et al. 1977). Sulfolane was removed from plasma with a half life of 3.5 to 5.0 hours (Andersen et al. 1977).

The metabolite of sulfolane is 3-hydroxysulfolane (Roberts and Warwick 1961). As dosage of sulfolane increases in rats, the proportion of sulfolane that is excreted unchanged increases, suggesting a saturable metabolic pathway (Andersen et al. 1977). When 100 mg of sulfolane was administered intraperitoneal (i.p.) to rats, 85% of the sulfolane was excreted as a metabolite, 3-hydroxy sulfolane, in the first 24 hours (Roberts et al. 1960).

Acute Toxicity Data

Acute health effects arise from exposure to a substance that occurs once or for only a short time (up to 14 days). Acute lethal dose testing of sulfolane reported in the open literature is shown in Table 2. Non-lethal testing is shown in Table 3. Limited data on the dermal irritancy and sensitivity of sulfolane suggest a low potential for sulfolane to be a sensitizer or an acute irritant in drinking water.

Lethal Dose

In lethal dose studies, sulfolane produced signs consistent with central nervous system toxicity (Table 2) (Andersen et al. 1976). Mice and rats assumed a hunched, retreating posture with front limbs braced wide, and tail erect (Andersen et al. 1976). They were also hyperreactive, showed increased responsiveness to auditory stimulation, and respired rapidly (Andersen et al. 1976). At lethal doses, rats and mice exposed to sulfolane had clonic-tonic convulsions which could occur spontaneously or could be induced by sharp, loud noises (Andersen et al. 1976). Because sulfolane causes a regulated hypothermia, the lethality of sulfolane was directly related to ambient temperature, i.e. lower temperature resulted in lower mortality in mice (Gordon et al. 1986). This effect could be the result of the lower temperature itself, or the lowered metabolism induced by the regulated hypothermic response (Gordon et al. 1986).

Table 2: Acute Lethality Values for Sulfolane

Species	Type	Route	Value	Source
Rat	LD-50	Oral	2342 mg/kg	(Zhu et al. 1987)
	LD-50	Oral	2100 mg/kg	(VKH Brown et al. 1966)
	LD -50	Oral	1846 mg/kg	(Andersen et al. 1976)
	LD-50	Oral	1965 mg/kg	(Smyth et al. 1969)
	LD-50	Intraperitoneal	1600 mg/kg	RTECS (NIOSH 2006)
	LD-50	Intraperitoneal	1598 mg/kg	(Andersen et al. 1976)
	LD-50	Subcutaneus	1620 µl/kg (2049 mg/kg)	RTECS
	LD -50	Subcutaneus	1606 mg/kg	(Andersen et al. 1976)
	LD-50	Intravenous	1094 mg/kg	(Andersen et al. 1976)
	LD-50	Skin	>3800 mg/kg	RTECS
	LC-50	Inhalation	4-hour, >1200 mg/m^3	(Andersen et al. 1977)
	Other (lethal convulsions, pulmonary hemorrhage)	Inhalation	17.5-hour, 3600 mg/m^3	(Andersen et al. 1977)

Mouse	LD-50	Oral	1900 mg/kg	RTECS
	LD-50	Oral	2504 mg/kg	(Zhu et al. 1987)
	LD-50	Oral	(1900-2500 mg/kg) *	(VKH Brown et al. 1966)
	LD-50	Intraperitoneal	1250 mg/kg	RTECS
	LD-50	Intraperitoneal	1270 mg/kg	(Andersen et al. 1976)
	LD-50	Intravenous	1080 mg/kg	RTECS
	LD-50	Intravenous	632 mg/kg	(Andersen et al. 1976)
	LD -50	Subcutaneus	1360 mg/kg	(Andersen et al. 1976)
Rabbit	LD-50	Skin	3180 µl/kg (4023 mg/kg)	RTECS
	LD-50	Intravenous	(640– 850 mg/kg) †	(Andersen et al. 1976)
	LD-50	Subcutaneus	(1900-3500 mg/kg) †	(Andersen et al. 1976)
Guinea pig	LD-50	Oral	1815 mg/kg	(Andersen et al. 1976)
	LD-50	Oral	1445mg/kg	(Zhu et al. 1987)
	LD-50	Intraperitoneal	1331mg/kg	(Andersen et al. 1976)
Monkey	Other (lethality-convulsions >25% reduction in white blood count >15% reduction in HGB and HCT	Inhalation	4850 mg/m^3	(Andersen et al. 1977)

* Authors provided only a range value of LD-50 without explanation

† Not enough animals were used to calculate an LD50, so only a range is given – all animals survived at the lower dose and all animals died at the higher dose.

Acute Toxicity

The acute effects of sulfolane have been studied by several researchers (Table 3). The effects of sulfolane noted have been changes in thermoregulation, changes in motor activity, and changes in brain-wave patterns in rats. As noted above, lethal doses of sulfolane result in neurotoxicity as demonstrated by clonic-tonic convulsions.

Neurotoxicity

Single intraperitoneal (i.p.) injections of 800 mg/kg and 400 mg/kg produced dose-dependent significant changes in flash evocated potentials (FEPs) and pattern-reversal evoked potentials (PREPs) (Dyer et al. 1986). These changes lasted over six hours after treatment, with effects diminishing with time. The 200 mg/kg dose did not produce a change in either FEPs or PREPs.

The 400 mg/kg and 800 mg/kg doses resulted in hypothermia in the rats. Changes in FEPs were not shown to be secondary to hypothermia in the rats. When hypothermia was prevented in the 800 mg/kg dose group of rats by keeping them in a warm ambient environment, sulfolane still resulted in changes in FEPs latencies. PREPs were not measured in the group in which hypothermia was prevented.

Burdette and Dyer (1986) conducted a series of experiments to identify sulfolane dosages that alter seizure susceptibility to confirm the results of previous studies that sulfolane-treated animals are hyper-reactive to sound. A second set of experiments was conducted to determine the potential interaction between hypothermia and the convulsant properties of sulfolane. I.p. doses of 800 mg/kg (one-half the lethal dose), 400 mg/kg, 200 mg/kg and 0 mg/kg (controls) were administered to young male Long Evans hooded rats. On stimulation, audiogenic seizures were observed in approximately half the animals treated with 800 mg/kg in both experiments. Rats administered 400 mg/kg demonstrated minimal seizure susceptibility in the first study, but not in the second. No seizure activity was seen in the 200 mg/kg or control animals. With respect to the susceptibility to audiogenic seizures, the authors reported that it was evident that hypothermia provided a significant protective influence, as inferred from the statistically significant decrease in seizure severity and duration. It was further concluded that sulfolane preferentially lowers seizure thresholds in select brain structures, rather than creating a general predisposition to seizures triggered by any mechanism.

Metabolic Changes and Thermoregulation

Gordon et al. (1985) measured effects in thermoregulatory responses in male Sprague-Dawley-rats that were injected (i.p.) with 800 milligrams per kilogram (mg/kg) sulfolane at ambient temperatures of 15 or 25 degrees-C. At ambient temperatures of either 15 or 25 degrees, sulfolane significantly inhibited metabolic rates and colonic temperatures. The metabolic rate was depressed for 4 hours post injection, gradually recovering thereafter. Colonic temperature was depressed for 8 hours after injection. Tail skin temperature was not affected by sulfolane at either ambient temperature. The authors suggest that recovery of the thermoregulatory function may parallel sulfolane clearance from the blood in rats.

Male rats were injected i.p with 0, 200, 400 or 800 mg/kg of sulfolane and placed in ambient temperatures of 15, 25 or 35 °C (Gordon et al. 1984). At 15 and 25 °C, 400 and 800 mg/kg of sulfolane resulted in statistically significant reduction in core body temperatures in the rats. Metabolism was statistically lower in the 800 mg/kg treatment groups at ambient temperatures of 15 and 25 °C. At 35 °C, no dose of sulfolane resulted in statistically significant reductions in core body temperature.

In a similar experiment, mice were treated with sulfolane (0, 200, 400, 600 and 800 mg/kg i.p.) and kept at ambient temperatures of 20, 30 and 35 °C (Gordon et al. 1986). Sulfolane caused a dose dependent and temperature dependent significant decrease in metabolism and colonic temperature at 400, 600 and 800 mg/kg in mice. At an ambient temperature of 35 °C, no statistically significant changes in metabolism or colonic temperature were measured. At 20 °C, statistically significant decreases in metabolism and colonic temperature were measured at 400, 600 and 800 mg/kg doses. At 30 °C, the statistically significant decreases in metabolism and colonic temperature occurred in the 600 and 800 mg/kg dose groups only.

Sulfolane can affect the preferred ambient temperature of mice (Gordon et al 1986). Mice treated with 400, 600, and 800 mg/kg (i.p.) preferred significantly lower ambient temperatures in a temperature gradient. After 1 hour, mice having received 600 and 800 mg/kg of sulfolane still preferred statistically lower temperatures. The authors also studied preferred ambient temperature in 800 mg/kg (i.p.) sulfolane treated rats (Gordon et al. 1985). Rats selected the same ambient temperature (20.7 degrees) as the controls 1 hour after injection. Over time, sulfolane treated rats preferred a statistically insignificant lower temperature than controls. At the end of 8 hours, the preferred ambient temperature of control and sulfolane treated animals had increased to 24.5 and 23.5 degrees, respectively.

Ruppert and Dyer (1985) investigated the effects of sulfolane on the behavior of rats at ambient temperatures which would either prevent (32.3 °C) or facilitate (20.8 °C) the development of hypothermia using figure-of-eight mazes. Behavior was assessed 1 hour after i.p. dosing of saline, 200, 400 or 800 mg/kg sulfolane. Sulfolane reduced activity in the rats in both temperature groups at 400 and 800 mg/kg doses. However, at the warmer temperature, the effects were produced without hypothermia. At 20.8°C , the decrease in behavior activity was more pronounced than the warmer temperature group.

Burdette and Dyer (1986) found that the affect of sulfolane on hypothermia was different in animals maintained at 29^{o}C (approx. 84^{o}F) compared with animals maintained at 23^{o}C (approx. 74^{o}F) during experimentation. At 29^{o}C, the housing temperature was sufficiently warm to control/prevent the dose-dependent hypothermia seen at 23^{o}C housing temperature in all groups. At the 23^{o}C housing temperature, colon temperatures decreased rapidly in the 800 mg/kg and 400 mg/kg groups by more than 3^{o}C during the first half hour following injection, after which the deep body temperature either stabilized or continued to decrease. The colonic temperatures remained significantly depressed for up to 8 hours in both of these high-dose groups. In the 200 mg/kg and control groups, there was a slow recovery after 3 hours, the deepest point of temperature depression.

Subcutaneous injections of sulfolane in rabbits at an ambient temperature of 10 °C caused a dose-dependent decrease in colonic temperature (Mohler and Gordon 1988). While the metabolic rate remained the same, a 1.5 °C transient increase in ear temperature and approximately 0.3 °C decrease in colon temperature were observed at 200 mg/kg (Mohler and Gordon 1988).The mechanism of toxicity in rabbits appears to be a result of changes in the vasomotor component of thermoregulation, whereas in rats and mice it appears that sulfolane induced hypothermia is caused by a reduction in metabolic rate (Gordon et al. 1985; Mohler and Gordon 1988).

Mohler and Gordon (1989) studied the thermoregulatory effects of sulfolane on the central nervous system of rabbits by microinjection of sulfolane into the region of the brain that controls thermoregulation. The rabbits were kept during treatment at an ambient temperature of 15 °C. Microinjection of saline, 100,300 or 1000 µg of sulfolane in saline into the preoptic/anterior hypothalamic area of the brains of rabbits did not result in regulated hypothermia. This suggests that the sulfolane is not directly acting on the center of thermoregulation in the brain. To evaluate whether changes in thermoregulation were the result of other centers of the brain being affected by sulfolane, Mohler and Gordon (1989) administered intracerebroventricular, (ICV) microinjection of sulfolane to rabbits. ICV microinjection of 300 and 1000 µg of sulfolane resulted in slight rise in the temperature of the preoptic/anterior hypothalamic area. An ICV injection 3000 µg of sulfolane caused a statistically significant hyperthermia in rabbits. At

10,000 µg ICV injection, sulfolane caused a slight decrease in the temperature of the preoptic/anterior hypothalamic area, followed by an increase in temperature. These data do not support the conclusion that sulfolane directly affects the centers of the brain involved in thermoregulation. However, the metabolite of sulfolane (3-hydroxy sulfolane) may act on these centers (Mohler and Gordon 1989).

Table 3: Acute Non-lethal Values for Sulfolane

Species	Type	Route	Value	Source
Rat	LOAEL (Thermoregulation)	Intraperitoneal (i.p.)	800 mg/kg	(Gordon et al. 1985)
	LOAEL (Thermoregulation)	i.p.	400 mg/kg	(Ruppert and Dyer 1985)
	NOAEL (Thermoregulation)	i.p.	200 mg/kg	(Ruppert and Dyer 1985)
	NOAEL (Thermoregulation)	i.p.	200 mg/kg	(Ruppert and Dyer 1985)
	NOAEL (Thermoregulation)	i.p.	200 mg/kg	(Burdette and Dyer 1986)
	NOAEL (Visual Evocated Potentials)	i.p.	200 mg/kg	(Dyer et al. 1986)
	LOAEL (Seizure susceptibility)	i.p.	400 mg/kg	(Dyer et al. 1986)
	NOAEL (Seizure susceptibility)	i.p.	200 mg/kg	(Dyer et al. 1986)
	LOAEL (Motor activity)	i.p.	400 mg/kg	(Ruppert and Dyer 1985)
Rabbit	LOAEL (Thermoregulation)	Subcutaneous (s.c.)	200 mg/kg	(Mohler and Gordon 1988)
Mouse	LOAEL (Thermoregulation)	i.p.	400 mg/kg	(Gordon et al. 1986)
	NOAEL (Thermoregulation)	i.p.	200 mg/kg	(Gordon et al. 1986)
	NOAEL (Developmental)	Oral	280 mg/kg	(Zhu et al. 1987)
	LOAEL (Developmental)	Oral	840 mg/kg	(Zhu et al. 1987)
	NOAEL (Genotoxicity)	Oral	62.5 mg/kg	(Zhu et al. 1987)
Dog	LOAEL – Neurological Convulsions Aggressive Behavior Effects	Inhalation (After 7 days)	200 mg/m^3	(Andersen et al. 1977)

Skin and Eye Irritation and Sensitivity

Limited information on skin and eye irritation has been reported in the literature. Smyth et al. (1969) report that sulfolane resulted in a "2" on a 10 point ordinal scale of irritation on

uncovered rabbit belly. The procedure for evaluation was observation of the severest reaction on the clipped skin of five albino rabbits within 24 hours of the uncovered application of 0.01 milliliters undiluted sample or solutions in water, propylene glycol, or acetone. Grade 1 indicated no irritation; grade 2 indicated the least visible capillary injection from the undiluted chemical. Grade 6 indicated necrosis when undiluted chemical was applied, and grade 10 indicated necrosis from a 0.01% solution. 1 milliliter of sulfolane per day applied and occluded did not produce irritation to bare rabbit skin (VKH Brown et al. 1966). 0.5 to 1 milliliter of sulfolane applied to bare skin of rabbits and guinea-pigs for five days per week for four and one half weeks did not result in gross or microscopic skin irritation (VKH Brown et al. 1966). Intradermal or topical application of sulfolane did not result in sensitivity (VKH Brown et al. 1966).

Smyth et al. (1969) rated eye injury in rabbits exposed to sulfolane as a "4" on a 10 point grading. The exact conditions or effects of the test were not reported, but a grade 1 indicated no irritation, and a grade of 5 indicated a severe burn with 0.005 ml (Smyth et al. 1962). We suspect that this means the substance was graded as moderately irritating to the eyes. However, Brown et al. (1966) reported that 0.2 ml of undiluted sulfolane applied to the right eyes of rabbits produced mild conjunctivitis which cleared within a few hours.

Due to the subjectivity of these tests and non-standardized laboratory practices at the time, moderate intra-laboratory reproducibility and low inter-laboratory reproducibility have been noted in these types of tests (Weil and Scala 1971). Therefore, some discrepancies in the results are not unexpected.

Developmental Effects

Sulfolane was orally administered to pregnant mice at doses of 93, 280, or 840 mg/kg (Zhu et al. 1987). Skeletal changes were found in the fetuses at the 840 mg/kg dose but not at the lower treatment dosages.

Genotoxicity

Mice were orally administered doses of 62.5, 125, 250, 500, or 1000 mg/kg. Using the mice marrow erythrocyte micronucleus test, sulfolane did not cause increases to the micronucleus counts in the mice marrow erythrocytes (Zhu et al. 1987).

Intermediate/Sub-Chronic Toxicity

Intermediate/sub-chronic toxic effects are a result of exposure to a substance that occurs for more than 14 days and less than a year. Sub-chronic studies are summarized in Table 4. Another study, published by Huntington Life Sciences was reported in other literature as a 13 week oral study (CCME 2006). This study reported a NOAEL of 2.9 mg/kg/day. This research, however, is not available due to proprietary agreements (Turner 2009).

Table 4: Sub- Chronic Studies of Sulfolane

Species	Effect	Route	Value	Source
Rat	NOAEL – Respiratory	Inhalation 23 hrs/day 5 days/week 90 DAYS	20 mg/m^3	(Andersen et al. 1977)

	LOAEL – Inflamed hemorrhagic lungs	Inhalation 23 hrs/day 5 days/week 90 DAYS	159 mg/m^3	(Andersen et al. 1977)
	LOAEL – Chronic inflammation	Inhalation 8 hrs/day 5 days/week 27 days	495 mg/m^3	(Andersen et al. 1977)
	NOAEL	Oral 90 days	167 mg/kg/day	(Zhu et al. 1987)
	LOAEL – Decreased ascorbic acid in adrenal glands	Oral 90 days	500 mg/kg/day	(Zhu et al. 1987)
	LOAEL – decreased birth index and number of pups (day 0 and 4 of lactation)	Oral 49 days (males) 41-50 days (females)	200 mg/kg/day	(OECD 2004)
	NOAEL – Reproductive Developmental	Oral 49 days (males) 41-50 days (females)	60 mg/kg/day	(OECD 2004)
Monkey	LOAEL – Death	Inhalation 8 hrs/day 5 days/week 27 days	495 mg/m^3	(Andersen et al. 1977)
Dog	NOAEL – Respiratory	Inhalation 23 hrs/day 5 days/week 90 DAYS	20 mg/m^3	(Andersen et al. 1977)
	LOAEL – Inflamed hemorrhagic lungs	Inhalation 23 hrs/day 5 days/week 90 DAYS	159 mg/m^3	(Andersen et al. 1977)
Guinea Pig	LOAEL - Hepatic Effects Changes in Serum ALP Changes in White Blood Cell count	Oral (6 months)	2.5 mg/kg/day	(Zhu et al. 1987)
	NOAEL	Oral (6 months)	0.25 mg/kg/day	(Zhu et al. 1987)

Death

Nine male monkeys were exposed to 495 mg/m^3 for 27 days (23 hrs/day, 5 days/week) (Andersen et al. 1977). Three died during the course of the exposure and 5 others were found to be at the point of death and were sacrificed. The monkeys were found to have blood tinged fluid around the eyes and very pale livers and hearts. Of the remaining six monkeys surviving, fatty metamorphosis of the liver was observed in five.

Respiratory Effects

Andersen et al. (1977) exposed rats, guinea pigs and dogs to inhalation concentrations of 2.8, 4.0, 20, 159 or 200 mg/m^3. Hemorrhagic, inflamed lungs were observed in all species at concentrations of 159 and 200 mg/m^3. Dogs and rats exposed to 495 mg/m^3 for 27 days had chronic lung inflammation (Andersen et al. 1977).

Skin Irritation

Repeated application of 1 ml sulfolane to the bare skin of rabbits and 0.5 ml for guinea pigs of undiluted sulfolane for 5 days/week for four and one-half weeks did not result in gross visible skin irritation or in microscopic findings (VK Brown et al. 1966).

Hematological Effects

At 500 mg/kg for 90 days in guinea pigs the ascorbic acid content in the adrenal glands decreased. No blood change parameters were noted in rats at doses of 55.6 and 167 milligrams/kilogram/day (mg/kg/d) (Zhu et al. 1987). Guinea pigs were exposed to sulfolane at oral dose levels of 0, 0.25, 2.5, 25, or 250 mg/kg/d for six months (Zhu et al. 1987). Marrow cell numbers were lower in the 2.5, 25 and 250 mg/kg/d dose groups than the control group.

Hepatic Effects

Guinea pigs exposed to 200 mg/m^3 for 90 days via inhalation showed fatty vacuolization in livers (Andersen et al. 1977). This was not observed at 2.8, 4, 20 or 159 mg/m^3. Nine male monkeys were exposed to 495 mg/m^3 for 27 days (23 hrs/day, 5 days/week) (Andersen et al. 1977). Between exposure days 7 and 17, eight of the monkeys died or were found to be at the point of death and sacrificed. Fatty metamorphosis of the liver was observed in 5/6 of the surviving monkeys.

Guinea pigs and rats were orally exposed to doses of 55.6, 167 or 500 mg/kg/d for 90 days. Serum ALP activity decreased in guinea pigs at 55.6 and 167 mg/kg/d (but not at 500 mg/kg/d) (Zhu et al. 1987). White blood cell counts decreased in all groups. Guinea pigs exposed to 159 or 200 mg/m^3 via inhalation showed leucopenia and increased plasma transaminase activity (Andersen et al. 1977). This was not observed at 2.8, 4 and 20 mg/m^3.

Guinea pigs were exposed to sulfolane at oral dose levels of 0, 0.25, 2.5, 25, or 250 mg/kg/d for six months (Zhu et al. 1987). Biochemical and pathological evaluations were conducted on a subset of each dose group following three months and six months of exposure. GPT (Glutamic-pyruvic transaminase), GOT (glutamic-oxaloacetic transaminase) and fatty deposits of the liver were observed in pathological examinations of the 2.5, 25 and 250 mg/kg/d dose groups. No pathological effects were noted at 0.25 mg/kg/d dose group.

Lymphoreticular Effects

In the Zhu et al. (1987) 6-month study, at three months and six months of exposure, shrinkage of the white pulp in the spleen was observed in the 2.5, 25 and 250 mg/kg/d guinea pig dose groups, but not in the control groups. In the 2.5 mg/kg/d, 25 mg/kg/d and 250 mg/kg/d dosage groups, a decrease in cell counts in spinal marrow was found.

Neurological Effects

In the inhalation toxicity study of dogs conducted by Andersen et al. (1977), four dogs were exposed to 200 mg/m^3 by inhalation. The dogs suffered intermittent convulsions after 7 days of exposure and displayed fiercely aggressive behavior towards each other and their handlers (Andersen et al. 1977). After 11 days, one dog in the exposure group was suffering generalized motor seizures. Another dog had to be removed due to extremely aggressive behavior. A third dog was removed from the experiment after 29 days because he had become too dangerous for his handlers. Exposure in this group was intended for 23 hr/day for 90 days.

Developmental/Reproductive Effects

A reproduction/developmental toxicity screening test [OECD 421]) was reported in an OECD report (OECD 2004). This study was conducted by Japanese Ministry of Health (MHW 1999) and the report was peer reviewed by OECD. Rats were dosed at 0, 60, 200, or 700 mg/kg/d by gavage for 41 to 50 days from 14 days prior to mating to day 3 of lactation. Some mortality occurred in the high-dose group. There was a decrease in body weight gain and food consumption for males and females during the pre-mating period at 700 mg/kg/d. The number of oestrus cycles was decreased in the 700 mg/kg/d group. Four dams lost all their pups during the lactation period in the 700 mg/kg/d group. Birth index, live index, number of pups on days 1 and 4 of lactation, viability index and body weights of pups of both sexes on days 0 and 4 of lactation decreased, and the number of still births increased in the 700 mg/kg/d group. Delivery and birth index were decreased in the 200 mg/kg/d group. The NOAEL for reproductive and developmental toxicity was 60 mg/kg/day. There were no treatment-related findings in the external appearance, general conditions and necropsy findings in offspring.

Chronic Toxicity

Chronic toxic effects arise from exposure that exceeds one year. No chronic toxicity studies have been identified by ATSDR. Only one open literature report of longer term sub-chronic toxicity was located by ATSDR (Zhu et al. 1987).

In Vitro Tests

In five bacterial strains (TA 1535, TA 1536, TA 1537, TA 98, and TA 100), sulfolane was not mutagenic in the presence or absence of S-9 activation at concentrations of 0, 2, 20, 200, or 2000 µg per plate (Zhu et al. 1987). Sulfolane did not have a significant effect on sister chromatid exchange in vitro in human peripheral blood lymphocytes (Zhu et al. 1987). OECD (2004) and CCME (2006) did not note that sulfolane was mutagenic in bacteria, nor did it induce chromosomal aberrations in mammalian cells in other unpublished tests they had obtained.

Quantitative Structure Toxicity Relationships

Quantitative Structure Toxicity Relationship (QSTR) has been used as a method for the estimation of sulfolane toxicity. QSTR utilizes a computer-based method to predict the toxicity of a chemical solely from its molecular attributes. TOPKAT/QSTR 6.2, a tool for structure-based toxicity assessment, correlates toxicity with a set of structural descriptors and gives a probability value between 0 and 1. A value between 0 - 0.3 is considered negative or of low probability; a value between 0.3 – 0.7 is considered indeterminate (i.e. (50/50 probability) for an assessment to be meaningful, and a value greater than 0.7 is considered positive.

TOPKAT automatically performs two analyses, the univariate analysis or coverage examination and the multivariate analysis or Optimum Prediction Space (OPS) examination to increase confidence in prediction. The univariate analysis checks whether all of the structural fragments of the query structure are represented in the data base compounds that were used in model development and that at least three compounds in the data-base have the same descriptors as that present in the query compound. In the event that structural attributes of these query compounds are not presented in the training set, the software warns the user of this fact and displays a message stating that the toxicity assessment may be unreliable. The multivariate analysis or OPS examination checks to see whether the submitted structure fits within or near the periphery of the OPS of the equation. If a query compound is determined to be outside the OPS, a warning about the acceptability of the assessment is displayed.

It is important to note that a query chemical being inside or near the periphery of the OPS does not necessarily mean that the predicted toxicity value for that chemical will have agreement with the experimental value. Rather, it implies that the model is applicable to that particular query compound and the probability of agreement between the experimental and predicted value is as high as that for the chemicals in the database.

QSTR models were used to evaluate the rodent oral carcinogenicity (female/male; rat/mouse), rat oral developmental toxicity and mutagenesis of sulfolane (Table 5).

Table 5: TOPKAT prediction of toxicity of sulfolane

Effect	Species	Result
Carcinogenicity	Rat (male)	Negative
	Rat (female)	Negative
	Mouse (male)	Negative
	Mouse (female)	Negative
Developmental Toxicity Potential		Positive
Mutagenesis Potential	Bacteria	Positive
LD50	Rat	1000 mg/kg (95% CI 202.2 mg/kg – 5100 mg/kg)

Skin Sensitization	Negative
Skin Irritation	Negative
Ocular Irritancy	Positive

Discussion

Sulfolane is acutely toxic at relatively high doses (over 200 mg/kg) in species tested. While the acute toxicity of sulfolane has been characterized in a number of species, a paucity of data exists on the longer term effects of sulfolane. Only one sub-chronic study, Zhu et al. 1987 was identified with effects noted in hepatic and lymphoreticular systems of rats (90 days) and guinea pigs (90 days and 6 months). An oral NOAEL for guinea pigs was identified as 0.25 mg/kg/day.

To assess the appropriate uncertainty and modifying factors, ATSDR considers the following facts:

- Guinea pigs were an order of magnitude (i.e., about 10-fold) more sensitive to sub-chronic effects than rats.
- QSTR methodology provides some assurance that sulfolane is probably not carcinogenic in either rats or mice. However, QSTR indicates that there is a potential for sulfolane to present developmental effects in animals. Developmental effects have been seen in two studies. Zhu et al. (1987) found developmental effects at a relatively high dose (½ the LD50) in mice. The Japanese Ministry of Health (JMH 1999) identified an oral developmental NOAEL of 60 mg/kg/day in rats and a LOAEL for developmental/reproductive effects at 200 mg/kg/day.
- No chronic toxicity studies could be identified for sulfolane.
- While the QSTR predicted a potential for there to be mutagenic effects, several tests both in vivo and in vitro have not noted mutagenicity.

Recommendations for Drinking Water at North Pole

A sub-chronic oral NOAEL of 0.25 mg/kg/day in guinea pigs was identified by Zhu et al. 1987. Utilizing an uncertainty of 10 for extrapolation from animals to humans is justified. To account for human variability, another uncertainty factor of 10 is applied. ATSDR therefore recommends that human exposures be limited to no more than 0.0025 mg/kg/day (2.5 µg/kg/day). Using standard water consumption assumptions (ATSDR 2005), this dose equates to the following action levels as protective of public health:

25 µg/l (ppb) for infant populations (Assumes 1 liter water per day at 10 kg bodyweight)

40 µg/l (ppb) for child populations (Assumes 1 liter water per day at 16 kg bodyweight)

87.5 µg/l (ppb) for adult populations (Assumes 2 liters water per day at 70 kg bodyweight)

Alternative Public Health Levels

The Canadian Council of Ministers of the Environment calculated a tolerable daily intake for sulfolane based on the Huntington Life Sciences NOAEL of 2.9 mg/kg/day in female rats

(CCME 2006, unpublished). Uncertainty factors of 10 for human to animal extrapolation, 10 for human variability, and 3 for extrapolation to chronic exposures as well as other database uncertainties was used. A total uncertainty factor of 300 was applied for a tolerable daily intake of 0.0097 mg/kg/day (9.7 µg/kg/day) Using default Canadian drinking water guidance, CCME derive a drinking water guidance value of 0.09 mg/l (90 µg/l or ppb) for adult receptors drinking 1.5 liters of water a day.

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Health Consultation

Sulfolane

May 2, 2011

Prepared by

Division of Toxicology and Environmental Medicine

Prevention, Response and Medical Support Branch

Emergency Response Team

Table of Contents

Introduction and Background

The Alaska Department of Health and Social Services requested that the ATSDR Division of Toxicology and Environmental Medicine review the chemical-specific health consultation for sulfolane issued in February 2010 (ATSDR 2010). Sulfolane has been detected in groundwater under the city of North Pole, Alaska. A completed exposure pathway connects sulfolane to North Pole residents through private and community wells. Alaska previously requested that ATSDR develop a public health action level for sulfolane in drinking water, as well as describe potential health effects of sulfolane exposure. The public health action level is a non-regulatory level set to identify whether human exposure needs further evaluation. ToxStrategies, a contractor for the site's potentially responsible party, provided an additional toxicological study of sulfolane and expressed concern about the methodology ATSDR employed in setting the action level for sulfolane (ToxStrategies 2010). ToxStrategies presented several alternative screening values, all derived with Benchmark Dose (BMD) methodology. ToxStrategies criticized ATSDR for not having done an independent dose-response analysis of the key study and for using semi-quantitative methods to derive its public health action level (ToxStrategies 2010). Additionally, ToxStrategies contended that there was no need to use child-specific intake factors to derive an action level (ToxStrategies 2010). ATSDR, as a matter of policy, will re-examine its decisions in the event that compelling new evidence or reasoning is presented.

BMD methods use nonlinear curve fitting software to fit a dose-response curve to the toxicological testing data. A point of departure, usually the 10% response rate (BMD_{10}) for dichotomous data or the 1 standard deviation (BMD_{1SD}) change in a continuous variable, is established. The methodology then calculates a lower statistical confidence on this BMD, referred to as the lower confidence limit of the benchmark dose (BMDL). ATSDR derived its 2010 sulfolane action level using a reported no observed adverse effect level (NOAEL) and dividing by uncertainty factors (UF). The BMD approach has several advantages over the NOAEL approach used by ATSDR (Crump 1984). Nevertheless, BMD methods require decisions such as appropriate model selection and restrictions on model parameters; these decisions can radically affect the BMDL reported. To be responsive to Alaska Department of Health and Social Services, ATSDR initially utilized the NOAEL/UF approach in its 2010 health consultation because default BMD models did not appear to adequately fit the data. Therefore, in light of these issues, this document reviews:

1. Does the new information warrant revision to the ATSDR recommendations for the site public health action level?
2. Do the data support the use of child-specific and infant-specific consumption and body weights in the public health action level of sulfolane?
3. What is the appropriate point of departure for setting a provisional health guidance value dose for sulfolane?

This document focuses on the above issues. Additional background information regarding what is known about toxicity of sulfolane is contained in the 2010 health consultation (ATSDR 2010).

Summary of Previous Health Consultation

Sulfolane is an industrial solvent used in liquid-liquid and liquid-vapor extraction of compounds such as aromatic hydrocarbons from petroleum (Brown et al. 1966; Andersen 1976; HSDB 2006). Sulfolane has also been reportedly used in fractionalization of wood tars, a component of hydraulic fluid, textile finishing, and as a curing agent in epoxy resins (HSDB 2006). Sulfolane is completely miscible in water, acetone, glycerol and many oils (Brown et al. 1966). Sulfolane has an odor threshold in water between 1.79 and 10.6 milligrams per liter (mg/L) (Zhu 1987 et al.). Sulfolane mixes well in water, is not very volatile, is not highly viscous, and is highly polar.

Sulfolane is acutely toxic at relatively high doses (over 200 millgrams per kilogram (mg/kg)) in several species tested (ATSDR 2010). While sulfolane's acute toxicity has been characterized in a number of species, only a limited number of studies examine longer-term exposure (Table 1). Of the available intermediate duration studies, Zhu et al. (1987) has been identified as the key study, with effects noted in hepatic and lymphoreticular systems of rats (90 days) and guinea pigs (90 days and 6 months). The study author identified an oral NOAEL for guinea pigs as 0.25 mg/kg/day. In its February 2010 health consultation, ATSDR applied an uncertainty factor of 100 to the NOAEL of 0.25 mg/kg/day (10 for extrapolation from animals to humans, 10 to account for human variability), resulting in a health guidance value dose of 0.0025 mg/kg/day (2.5 micrgorams/kilogram/day (µg/kg/day)). Using standard water consumption assumptions (ATSDR 2005), this sulfolane dose would equate to the following action levels:

- 25 parts-per-billion[1] (ppb) for infant populations (assumes 1 liter water per day at 10 kg bodyweight)
- 40 ppb for child populations (assumes 1 liter water per day at 16 kg bodyweight)
- 87.5 ppb for adult populations (assumes 2 liters water per day at 70 kg bodyweight)

Utilizing BMD methods, and after consultation with members of the ATSDR Minimal Risk Level Committee, ATSDR now recommends:

- 20 ppb for infant populations (Assumes 1 liter water per day at 10 kg bodyweight)
- 32 ppb for child populations (Assumes 1 liter water per day at 16 kg bodyweight)
- 70 ppb for adult populations (Assumes 2 liters water per day at 70 kg bodyweight)

Discussion

BMDS analysis of Available Intermediate Duration Studies

An ad hoc committee of ATSDR's Minimal Risk Level (MRL) workgroup convened to review and discuss the February 2010 Health Consultation of sulfolane, and to review the information and issues raised by ToxStrategies in its August 2010 sulfolane assessment. These recommendations were further reviewed with toxicologists—including experts in Benchmark Dose Modeling—at the U.S. Environmental Protection Agency (USEPA), The U.S. Food and Drug Administration, and the National Institute for Occupational Safety and Health. For the derivation of a health guidance sulfolane value, ATSDR considered three intermediate exposure

[1] 1 part-per-billion of sulfolane is equivalent to 1 microgram of sulfolane per liter of water

duration studies[2] (Table 2). ATSDR has been unable to locate chronic studies on sulfolane. ATSDR used U.S.EPA's Benchmark Dose Modeling System (BMDS) version 2.12 to establish BMDLs for each of the studies and their health effects (Appendix B) (USEPA 2010a).

Zhu et al. 1987

The Zhu et al. study (Table 3), reports an intermediate-duration oral study of guinea pigs (Zhu et al. 1987). The manner and schedule of oral administration is not specified. This introduces some uncertainty in the dosing. If the animals were gavaged on a less-than 7 day per week schedule for the study duration, the average dose could be potentially less than the administered dose. Zhu et al.'s purported purpose was to derive a cumulative toxicity value for sulfolane in drinking water. The authors specifically report a chronic threshold dose of 2.5 mg/kg and a NOAEL of 0.25 mg/kg, suggesting that these values were averaged over the study's duration. ATSDR assumes the chronic dose was accurately reported.

For the Zhu et al. study, ATSDR considered the following toxic end points: shrinkage of the white pulp of the spleen at 3 months and 6 months, and fatty degeneration of the liver at 6 months. The study noted changes in blood chemistry and cell counts in the bone marrow, but the lack of reporting of parameter variability details prevent a full dose-response analysis. ATSDR does not use severe health effects to establish a point of departure. Thus, severe fatty degeneration of the liver was not modeled. The liver and spleen effects, however, showed a significant trend (using the Cochran-Armitage test for trend). Compared with controls, Fisher's Exact test p-values decreased with dose in the 3-month spleen data and in the 6-month liver and spleen data. P-values were below the standard statistical-significance threshold (less than 5% chance of no difference, $p<0.05$) at 250 mg/kg/day. Borderline statistical significance ($p=0.054$) occurred at 25 mg/kg/day. Multiple comparison adjustment (e.g., Holm's correction) was not used because Fisher's Exact Test will fail to reject the null hypothesis at a rate far less than it nominally reports (Armitage et al. 2002; Lin and Yang 2009).

For fatty liver degeneration effects in the Zhu et al. study, ATSDR considered the primary and alternative models in the BMDS. ATSDR utilized the BMDS models with restrictions on parameters—as recommended in the BMDS system—and also without restrictions. While several of the primary models passed the X^2 criterion of $p >0.1$ (Appendix B, Table B-1), boundary restrictions constrained all of the primary models' parameters. The literature has discussed some statistical issues and concerns that arise when a model parameter hits a boundary restriction (Kopylev and Fox 2009) with respect to derivation of BMDLs. This is illustrated by the magnitude of the changes observed in BMDL's and goodness-of-fit measures, when the restrictions are removed from the models. The purpose of parameter boundary restrictions are to prevent the occurrence of unrealistic model predictions. For example, the restriction on slope in the log-logistic model prevents an unrealistically high dose-response rate at very low doses. Accurate assessment of the dose response data is critical for ATSDR's public health assessment process (cf. ATSDR Public Health Assessment Guidance Manual, chapter 8) (ATSDR 2005). Thus, ATSDR considered alternative models in BMDS, with USEPA recommended restrictions on the parameters. Of the alternatives, the restricted dichotomous Hill model provided superior fits to the Zhu et al. fatty liver dose-response data than did the restricted log-logistic model. In

[2] ATSDR considers intermediate exposure to be from 2 weeks to 1 year.

fact, the dichotomous Hill model is similar to the log-logistic model, and two of the four ATSDR external reviewers recommended it. The restricted dichotomous Hill model predicted the BMDL for the liver effect seen in Zhu et al. as 2.4 mg/kg/day.

Likewise, in evaluating the 6-month spleen data, the restricted dichotomous Hill model best described the dose response data, as measured by higher X^2, lower Akaike information criterion (AIC), and lower residuals (Appendix B, Table B-2). While passing the X^2 criterion, parameter boundaries constrained the primary models. The restricted dichotomous Hill model predicted a BMDL for sulfolane of 1.5 mg/kg/day.

For the 3-month spleen dichotomous data, ATSDR considered all the primary and alternative models with and without recommended restrictions on model parameters (Appendix B, Table B-3). The dichotomous Hill model, Zhu et al. better fit the data than other restricted models, and predicted a BMDL at 1.5 mg/kg/day.

Huntingdon Life Sciences 2001

Huntingdon Life Sciences (HLS) (2001) conducted a detailed 90-day study of male and female rats exposed to sulfolane in their drinking water *ad libitum.* This administration mode may be more relevant to water contamination than is oral gavage, because in a gavage study the animals typically receive a bolus dose of the contaminant on a daily basis, whereas with a drinking water study the animals would receive their dose gradually as they drink water. While good laboratory practices (GLP) governed this study, the study is not available in the open, peer-reviewed literature.

Only 10 rats per sex per dose group were exposed. At the time of ATSDR's original health consultation, this study was unavailable to the agency for review, although summaries were available (CCME 2006). ToxStrategies obtained a copy of this study and later provided it to ATSDR. In the study, HLS researchers conducted a comprehensive battery of observations (weight, food/water intake, reflexes, and behavior), examined 13 major organ systems (adrenals, brain, femur, heart, ileum, kidneys, liver, lungs, mammary area, spinal cord, stomach, thyroid, and uterus), and performed hematological examination and chemical analysis of the blood. The only reported significant effect relevant to human health was a reduction of white blood cell and lymphocyte counts in female rats (NOAEL=2.9 mg/kg/day). The HLS study does increase the data available for development of a health-based guidance value. However, the rats in the HLS study did not suffer from fatty degeneration of the liver or from effects on the spleen, even at doses as high as 191 mg/kg/day. This suggests rats are not the most sensitive species. Furthermore, Zhu et al. (1987) studied rats concurrently with guinea pigs, and concluded that the guinea pig appeared to be the species more sensitive to sulfolane's effects. In the absence of adequate human data, ATSDR will normally select the most sensitive animals and endpoints for derivation of health guidance values. Nevertheless, others have recommended the HLS study for deriving health guidance values. The Canadian Council of Ministers of the Environment (CCME) calculated a tolerable daily intake for sulfolane based on the HLS NOAEL of 2.9 mg/kg/day in female rats (CCME 2006). CCME used uncertainty factors of 10 for human to animal extrapolation, 10 for human variability, and 3 for extrapolation to chronic exposures, as well as other database uncertainties. Thus, CCME applied a total uncertainty factor of 300 for a tolerable daily intake of 0.0097 mg/kg/day (9.7 µg/kg/day). Using default Canadian drinking

water guidance, CCME derived a sulfolane drinking water guidance value of 0.09 mg/l (90 µg/l or ppb) for adult receptors drinking 1.5 liters of water per day.

In contrast, ToxStrategies used benchmark dose modeling to fit a linear model of the log-transformed dose (ln (dose+1)) to the reduced total white blood celland lymphocyte data (ToxStrategies 2010). As these measures were continuous measurements, the benchmark response dose represents a 1 standard deviation reduction in laboratory historical female rat white blood cell counts. ATSDR repeated this analysis using BMDS, but also considering concurrent and historical controls.[3] BMD models for the reduction in monocytes, basophils, and large unstained cells did not meet statistical tests for fit, nor did they produce a valid answer (i.e., BMDL <0). ToxStrategies arrived at a "Reference Dose" of 0.01 mg/kg/day (Table 4) by selecting the linear model based on parsimony and applying a ¾ power body weight scaling and standard uncertainty factors.

Results of ATSDR's modeling of the HLS data (with and without substitution of historical control data) are shown in Appendix B, Tables B-4 through B-7. Because the polynomial and the power models resulted in models identical to the linear model, these results are not presented. Following USEPA guidance on model selection, when the BMDLs differ by a factor greater than three, the lowest BMDL is recommended (USEPA 2000). When the BMDLs are within a factor of three, the lowest AIC is chosen. Or, if multiple values have the same AIC, then an average is recommended (USEPA 2000). Parsimony does not provide much guidance on model selection because the linear and exponential regressions are equally parsimonious as applied to the log-transformed HLS data. Algebraic reduction of the linear model results in an equation with a logarithm function:

$$Y[dose] = beta_0 + beta_1 * (\ln(1 + dose))$$

the exponential (M2) model reduces to:

$$Y[dose] = a \times (dose + 1)^{-b}$$

the exponential (M4) model reduces to:

$$Y[dose] = a \times c \times (c - 1) \times (dose + 1)^{-b}$$

In terms of functions and number of variables, the M2 and the linear models are equally complex. In considering the exponential equation, exponential submodel M2 and M4 resulted in identical curves (in this case c=0). The difference in BMDL is a result of submodel M4 having an additional parameter. In the regressions, as the BMDS searched for a $BMDL_{1SD,}$ this additional parameter increased the likelihood of the $BMDL_{1SD}$.

The BMDL is dependent on model-selection as well as controls. Unfortunately the statistical indicators (AIC, X^2) do not-provide a clear indication as to which model is preferable for any of the endpoints. ATSDR selected the lowest BMDL values to evaluate whether the HLS data had a higher BMDL than did the Zhu et al. guinea pig data. Regardless of the model selected however, the BMDLs from the HLS 2001 are higher than those in the Zhu et al. study. The lowest BMDL

[3] ATSDR noted that the WBC standard deviation of the highest dose group in the female rats is 1.019. ToxStrategies modeled the standard deviation as 1.109 (cf ToxStrategies 2010 p 53). ATSDR also noted also that some animal blood samples were clotted and not readable, resulting in fewer than 10 blood samples in some dose groups.

would have been the exponential M4 lymphocyte-reduction model. If concurrent controls were used, and if historical controls were used in the BMDS, this model would have resulted in a BMDL of 4.12 or 4.38, based on the lowest AIC for this effect.

Japanese Ministry of Health 1999

A 2004 Organization for Economic Cooperation (OECD) report (OECD 2004) contained a reproduction/developmental toxicity sulfolane screening test study. The Japanese Ministry of Health (MHW 1999) conducted the study, which OECD peer-reviewed. Rats were dosed at 0, 60, 200, or 700 mg/kg/day of sulfolane by gavage for 41 to 50 days from 14 days before mating to day 3 of lactation. Some mortality occurred in the high-dose group. During the pre-mating period , a decrease in body weight gain and food consumption occurred for both males and females at a dose of 700 mg/kg/day. The number of estrus cycles also decreased in the 700 mg/kg/day group. In the 700 mg/kg/day group, four dams lost all their pups during the lactation period. Birth index, live index, number of pups alive on days 1 and 4 of lactation, viability index, and body weights of pups of both sexes on days 0 and 4 of lactation all decreased at this dose. In addition, the number of stillbirths increased. In the 200 mg/kg/day group, delivery and birth index also decreased. The NOAEL for reproductive and developmental toxicity was 60 mg/kg/day. However, at 60 mg/kg/day, no treatment-related observations were recorded in the external appearance, general conditions and necropsy findings in offspring.

The BMDS successfully fit $BMDL_{1SD}$ models to both the birth index and the number of live pups. $BMDL_{1SD}$ for the live pups on day 4 was 160 mg/kg/day (exponential model M3) and for birth index, the BMDL established was 120 mg/kg/day (exponential model M3). Results are shown in Tables B-8 and B-9 in Appendix B. As discussed in ATSDR's original health consultation, developmental effects occur at relatively high sulfolane doses (half of the lethal dose) and probably are not sensitive endpoints for basing a provisional health guidance value.

Selection of Study and Endpoint

ATSDR has selected the Zhu et al. study for the derivation of the provisional health guidance value. It has the advantage of having been conducted for the longest period of time (twice the duration of the HLS study). Another key advantage of the Zhu et al. study is that it is available in the peer-reviewed literature, although in Chinese.

ATSDR received criticism (ToxStrategies 2010) for selecting the Zhu et al. study because:

1. The Zhu et al. study lacked standard deviations of the bone marrow and hepatic enzymes, preventing independent verification and analysis of cell counts in the blood and bone marrow and hepatic enzyme levels in the blood.

2. Zhu et al. did not provide incidence or standard deviation data for the 90-day rat and guinea pig study.

3. ATSDR was unclear regarding the endpoint from which it derived its public health action level.

In response, ATSDR notes that despite the HLS study's extensive pathological examinations, no changes to the liver or spleen were noted (HLS 2001; ToxStrategies 2010). Zhu et al. also studied rats over 90 days together with guinea pigs, and noted that with respect to sulfolane, guinea pigs were the more sensitive species. While Zhu et al. contains acknowledged

uncertainties, the lack of some parameters does not automatically invalidate other data on which the study relies. Using BMD analysis, the most sensitive departure point is a BMDL for dispersion of the white pulp of the spleen at 1.5 mg/kg/day in the guinea pig.

ATSDR Derivation of Action Level using Zhu et al. *1987*

Use of BMD methodology outlined above would alter ATSDR's recommended public health action levels (Table 5). Using the 1.5 mg/kg/day BMDL (dispersion of the spleen's white pulp), we recommend a total uncertainty factor of 1000 (10 for animal to human extrapolation, 10 for variability in human sensitivity, and 10 for extrapolation of an intermediate dose to a chronic dose), resulting in a sulfolane action level of 0.002 mg/kg/day. The additional uncertainty factor for intermediate to chronic exposure, as compared with ATSDR's 2010 Health Consultation, is added to account for the longer duration of exposure apparently occurring at this site.

Child-Specific Intake Factors

ATSDR's use of child-specific intake factors for health guidance values is outlined in the Public Health Assessment Guidance Manual (ATSDR 2005) and is established policy at the agency. ToxStrategies cites the USEPA Region III Risk Based Concentration (RBC) intake and bodyweight factors as a justification for using adult body weight (70 kilograms) and water intake (2 liters per day) (ToxStrategies 2010). ATSDR's public health action levels were based on body weights specific for age categories (infant = 10 kg, child = 16 kg, and adult = 70 kg) and intake factors (child/infant = 1 liter per day, adult = 2 liters per day).

The RBC purpose and the ATSDR screening value purpose, while similar, are not identical. The RBC's tables stated purposes are (USEPA 2010b):

- Prioritizing multiple sites or operable units or areas of concern within a facility or exposure units
- Setting risk-based detection limits for contaminants of potential concern (COPCs)
- Focusing future site investigation and risk assessment efforts (e.g., selecting COPCs for the baseline risk assessment)
- Identifying contamination that may warrant cleanup
- Identifying sites, or portions of sites, that warrant no further action or investigation
- Initial cleanup goals when site-specific data are lacking

The ATSDR action level is specifically designed to support screening of environmental data using the process outlined in the ATSDR Public Health Guidance Manual (PHAGM). This is distinct from the purposes outlined above for the RBCs (ATSDR 2005). Simply put, an action level is intended to serve only as a screening tool to help decide whether to evaluate more closely exposures to a substance found at a site (ATSDR 2005). Exceeding the recommended action level supports the need for additional assessment of site conditions. Some of the elements that assessment might include activities outlined in Chapter 8 of the PHAGM. That is, at the location where the action levels are exceeded, the assessment might include a review of the specific demographics of the population exposed. ATSDR requires consideration of children's health issues at all sites (PHAGM 8.5.3). Given the developmental effects reported in OECD (2004),

the use of child and infant-specific intake factors is a prudent way to ensure protection for these sensitive populations.

Uncertainties

As mentioned in the discussion of the Zhu et al. study, the exact mode of administration for sulfolane is not known. Depending on the dosing schedule, the mode of administration could affect the dose value calculation. However, that said, the authors report the values used as "chronic values," and the study was clearly directed towards deriving drinking water toxicity values. Thus, the reported doses were in all likelihood accurately reported. The alternative Huntingdon Life Science study is not available in the open peer-reviewed literature. Zhu et al., in side–by-side comparison of 90-day studies of both guinea pigs and rats, found guinea pigs to be the more sensitive species (Zhu et al. 1987). Not surprisingly, the HLS data in a 90-day study failed to find histopathological changes in rat livers. This was consistent with Zhu et al.'s findings. ATSDR's dose-response analysis, using USEPA's BMDS, looked at both the Zhu et al. data and the HLS data. ATSDR found the lowest benchmarks with the Zhu et al. guinea pig data.

In addition to drinking water, Alaska health officials are considering and evaluating other exposure routes. The Alaska Department of Health and Social Services reported that sulfolane was detected in relatively low concentrations in a small sample of garden produce that was watered with well water containing sulfolane (ADHSS 2011). Additional exposure pathways may be present through inhalation of water vapor containing sulfolane during showering, bathing, and dishwashing. However, because sulfolane has a relatively low vapor pressure, ATSDR did not address this pathway in its 2010 consultation. ATSDR understands, however, that USEPA is in the process of developing a Provisional Peer Review Toxicity inhalation value for sulfolane (State of Alaska 2011).

This health consultation does not consider exposure to additional chemicals in the environment. This introduces a slight uncertainty because the presence of other chemicals can sometimes amplify a given chemical's toxicity (ATSDR 2005; Chou 2002). Examining multiple chemical exposures in the context of Public Health Assessments/Consultations is addressed in ATSDR's *Guidance Manual for the Assessment of Joint Action of Chemical Mixtures* and in ATSDR's *Public Health Assessment Guidance Manual* (ATSDR 2001; ATSDR 2005).

Recommended Public Health Action Levels

Using the provisional health guidance value of 0.002 mg/kg/day, ATSDR recommends the following environmental public health action levels for chronic (greater than 1-year) sulfolane exposure:

- 20 ppb for infant populations (assumes 1 liter water per day at 10 kg bodyweight)
- 32 ppb for child populations (assumes 1 liter water per day at 16 kg bodyweight)
- 70 ppb for adult populations (assumes 2 liters water per day at 70 kg bodyweight)

Conclusions

- The Zhu et al. (1987) study of sulfolane represents the longest period of exposure studied in the most sensitive animal. Using this study, ATSDR's BMDS analysis showed the lowest BMDL endpoints (shrinkage of the spleen's white pulp).
- For deriving a point of departure, the alternative dichotomous Hill model's (restricted slope) lowest BMDL using the Zhu et al. data is 1.5 mg/kg/day.
- To support the intended use in the context of public health assessment, child and infant factors are appropriate. Other contexts might require different exposure factors to derive an appropriate screening value, but for public health assessments ATSDR is mandated to consider children's health issues.
- A total uncertainty factor of 1000 is recommended (10 for animal to human extrapolation, 10 for variability in human sensitivity, and 10 for extrapolation of a intermediate duration dose to a chronic dose), resulting in an action level of 0.002 mg/kg/day. This computes to a similar, 2010 action level—as ATSDR previously recommended—of 0.0025 mg/kg/day.

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A peer review panel was assembled for this health consultation. The panel consisted of the following members:

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Scientists from the Agency for Toxic Substances and Disease Registry (ATSDR) have reviewed the peer reviewers' comments and determined which comments will be included in the profile. A listing of the peer reviewers' comments not incorporated in the profile, with a brief explanation of the rationale for their exclusion, exists as part of the administrative record for this compound.

The citation of the peer review panel should not be understood to imply its approval of the profile's final content. The responsibility for the content of this profile lies with the ATSDR.

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Appendix A – Tables

Table 1: Intermediate Duration Studies of Sulfolane

Species	Effect	Route	Value	Source
Rat	NOAEL* – Respiratory	Inhalation 23 hrs/day 5 days/week 90 days	20 mg/m^3	(Andersen et al. 1977)
	LOAEL† – Inflamed hemorrhagic lungs	Inhalation 23 hrs/day 5 days/week 90 days	159 mg/m^3	(Andersen et al. 1977)
	LOAEL – Chronic inflammation	Inhalation 8 hrs/day 5 days/week 27 days	495 mg/m^3	(Andersen et al. 1977)
	NOAEL	Oral (drinking water) 90 days	2.9 mg/kg/day	(HLS 2001)
	LOAEL – decreased lymphocyte, white blood cells, monocytes, and large unstained cell counts in females	Oral (drinking water) 90 days	10.6 mg/kg/day	(HLS 2001)
	NOAEL	Oral, 90 days	167 mg/kg/day	(Zhu et al. 1987)
	LOAEL – Decreased ascorbic acid in adrenal glands	Oral, 90 days	500 mg/kg/day	(Zhu et al. 1987)
	LOAEL – decreased birth index and number of pups (day 0 and 4 of lactation)	Oral 49 days (males) 41-50 days (females)	200 mg/kg/day	(JMH 1999/OECD 2004)
	NOAEL – Reproductive Developmental	Oral 49 days (males) 41-50 days (females)	60 mg/kg/day	(JMH 1999/OECD 2004)
Monkey	LOAEL – Death	Inhalation 8 hrs/day 5 days/week 27 days	495 mg/m^3	(Andersen et al. 1977)
Dog	NOAEL – Respiratory	Inhalation 23 hrs/day 5 days/week 90 DAYS	20 mg/m^3	(Andersen et al. 1977)
	LOAEL – Inflamed hemorrhagic lungs	Inhalation 23 hrs/day 5 days/week 90 DAYS	159 mg/m^3	(Andersen et al. 1977)

Guinea Pig	LOAEL - Hepatic Effects Changes in Serum ALP Changes in White Blood Cell count	Oral (6 months)	2.5 mg/kg/day	(Zhu et al. 1987)
	NOAEL (reported by author)	Oral (6 months)	0.25 mg/kg/day‡	(Zhu et al. 1987)

*NOAEL: No Observed Adverse Effect Level

†LOAEL: No Observed Adverse Effect Level

‡ Author reported NOAEL as 0.25 mg/kg/day but statistical analysis showed NOAEL to probably be at the 2.5 mg/kg/day level.

Table 2 – Studies Considered in Provisional Health Guidance Value

Study	*Animal*	*Period of Study*	*Doses (mg/kg/day)*	*Route*	*Critical Effects*
Zhu *et al*. 1987	Guinea Pig	6 months, 3 months	0,0.25,2.5,25,250	Oral	Fatty degeneration of the liver, Dispersion of the white pulp of the spleen, , reported changes in AST and ALT
Huntingdon Life Sciences 2001	Rat	90 days	0, 2.9, 10.6, 42, 191.1	Oral (drinking water)	White blood cell counts decreased, Lymphocytes decreased in females at 10.6, 42, and 191.1 mg/kg/day
JMH 1999/OECD 2004	Rat	49 days (males) 41-50 days (females)	60, 200, 700 mg/kg/day	Oral (gavage)	Birth index, decreased number of pups alive at day 0 and day 4

Table 3 – Zhu et al. toxicity data (Guinea Pig)

Oral Dose (mg/kg/day)	*Spleen (3-month)*	*Spleen (6-month)*	*Fatty Liver (6-month)*	*Severe Fatty Liver (6-month)*	*Bone Marrow Count*
0	0/14	0/25	0/25	0/25	$16.43 \times 10^4/mm^3$
0.25	0/14	0/22	0/22	0/22	n.d.
2.5	1/14	2/26	2/26	1/26	$10.99 \times 10^4/mm^3$
25	2/14	2/25	4/25 (p=0.054) *	2/25	$12.25 \times 10^4/mm^3$
250	6/14 (p=0.008)*	7/22 (p=0.0027) *	7/22 (p=0.0027) *	5/22 (p=0.017) *	$10.56 \times 10^4/mm^3$
Cochran-Armitage Trend (p-value)	2.04×10^{-4}	2.04×10^{-4}	1.22×10^{-4}	7.09×10^{-4}	NA

*** Significant by Pair-wise Fisher Exact test vs. control (p≤0.05)**

Table 4 – ToxStrategies RfD for HLS 2001 Reduction in White Blood Cells in Rats

Point of Departure (mg/kg/day)	*Dose Scaling Factor*	*Human Equivalent Dose (mg/kg/day)*	*Uncertainty Factors*					*RfD dose*
			A	**H**	**S**	**D**	**Total**	
15.1	4.08	3.7	3	3	10	3	270(300)*	0.012 (0.01)*

A: Animal to human extrapolation
H: Human variability uncertainty factor
S: Extrapolation from intermediate duration to chronic exposure
D: Database uncertainties
* Value rounded to 1 significant figure

Table 5 – ATSDR provisional Health Guidance Level (p-HGV) for Sulfolane based on Zhu et al. 1987

Source	*Point of Departure (mg/kg/day)*	*Uncertainty Factors*					*p-HGV (dose)*
		A	**H**	**S**	**D**	**Total**	
Zhu et al. – Spleen	1.5	10	10	10	_	1000	0.002

A: Animal to human extrapolation
H: Human variability uncertainty factor
S: Extrapolation from intermediate duration to chronic exposure
D: Database uncertainties

Appendix B – Benchmark Dose System Output Summary

Table B-1: Zhu et al. 1987: Liver

Summary Table of BMDS modeling results

Liver (Zhu et al. 1987)						
Model	**Degrees of Freedom**	**X^2 *p*-Value**	**AIC**	**BMD (mg/kg-d)**	**BMDL (mg/kg-d)**	**Notes**
Gamma	3.00	0.15	74.00	62.78	34.84	power bound hit (power = 1)
gamma, unrestricted	3.00	0.84	68.94	10.41	1.09	unrestricted (power = 0.385)
log-logistic	3.00	0.17	73.47	48.51	22.63	slope bound hit (slope = 1)
log-logistic, unrestricted	3.00	0.87	68.75	9.45	1.21	unrestricted (slope = 0.462)
log-probit, unrestricted	3.00	0.90	68.49	8.56	1.33	unrestricted (slope = 0.252)
multistage, 4-degree	3.00	0.15	74.00	62.78	34.84	final ß = 0
Weibull	3.00	0.15	74.00	62.78	34.84	power bound hit (power = 1)
Weibull, unrestricted	3.00	0.86	68.84	9.92	1.15	unrestricted (power= 0.343)
quantal linear	3.00	0.15	74.00	62.78	34.84	
dichotomous Hill [a]	3.00	0.84	68.58	5.88	2.40	slope bound hit (slope = 1)
dichotomous Hill, unrestricted	2.00	0.75	70.41	6.94	1.34	
log-Probit, background dose, unrestricted	3.00	0.90	68.49	8.56	1.33	
Weibull, unrestricted	3.00	0.86	68.84	9.92	1.15	

[a] Best-fitting model, BMDS output presented in this appendix

Output for selected model: dichotomous Hill

Zhu et al. 1987: Liver

```
================================================================
        Dichotomous Hill Model. (Version: 1.2; Date: 12/11/2009)
```

```
         Input Data File: C:/USEPA/BMDS212/Data/1A_Zhu_1987_Liver_DichHill_dich_hill_liver.(d)
         Gnuplot Plotting File:
C:/USEPA/BMDS212/Data/1A_Zhu_1987_Liver_DichHill_dich_hill_liver.plt
                                                    Tue Feb 08 13:54:53 2011
 ========================================================================

 [add_notes_here]
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

   The form of the probability function is:

   P[response] = v*g +(v-v*g)/[1+EXP(-intercept-slope*Log(dose))]

        where: 0 <= g < 1, 0 < v <= 1

               v is the maximum probability of response predicted by the model,

               and v*g is the background estimate of that probability.


   Dependent variable = y
   Independent variable = dose
   Slope parameter is restricted as slope >= 1

   Total number of observations = 5
   Total number of records with missing values = 0
   Maximum number of iterations = 250
   Relative Function Convergence has been set to: 1e-008
   Parameter Convergence has been set to: 1e-008



                  Default Initial Parameter Values
                              v =        -9999
                              g =        -9999
                      intercept =     -5.81209
                          slope =            1


           Asymptotic Correlation Matrix of Parameter Estimates

           ( *** The model parameter(s)  -g    -slope
                 have been estimated at a boundary point, or have been specified by the user,
                 and do not appear in the correlation matrix )

                        v    intercept

         v              1        -0.74

 intercept        -0.74            1



                                Parameter Estimates

                                                          95.0% Wald Confidence Interval
       Variable         Estimate        Std. Err. Lower Conf. Limit   Upper Conf. Limit
              v         0.303254         0.108989          0.0896387            0.516869
              g                0              NA
      intercept         -2.47993          1.15449             -4.7427           -0.217172
          slope                1              NA

NA - Indicates that this parameter has hit a bound
     implied by some inequality constraint and thus
     has no standard error.


                        Analysis of Deviance Table
```

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-31.8035	5			
Fitted model	-32.2879	2	0.96878	3	0.8088
Reduced model	-41.162	1	18.717	4	0.0008932

AIC: 68.5757

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.0000	0.000	0.000	25	0.000
0.2500	0.0062	0.137	0.000	22	-0.371
2.5000	0.0525	1.365	2.000	26	0.558
25.0000	0.2052	5.131	4.000	25	-0.560
250.0000	0.2894	6.367	7.000	22	0.297

Chi^2 = 0.85 d.f. = 3 P-value = 0.8371

Benchmark Dose Computation

Specified effect = 0.1

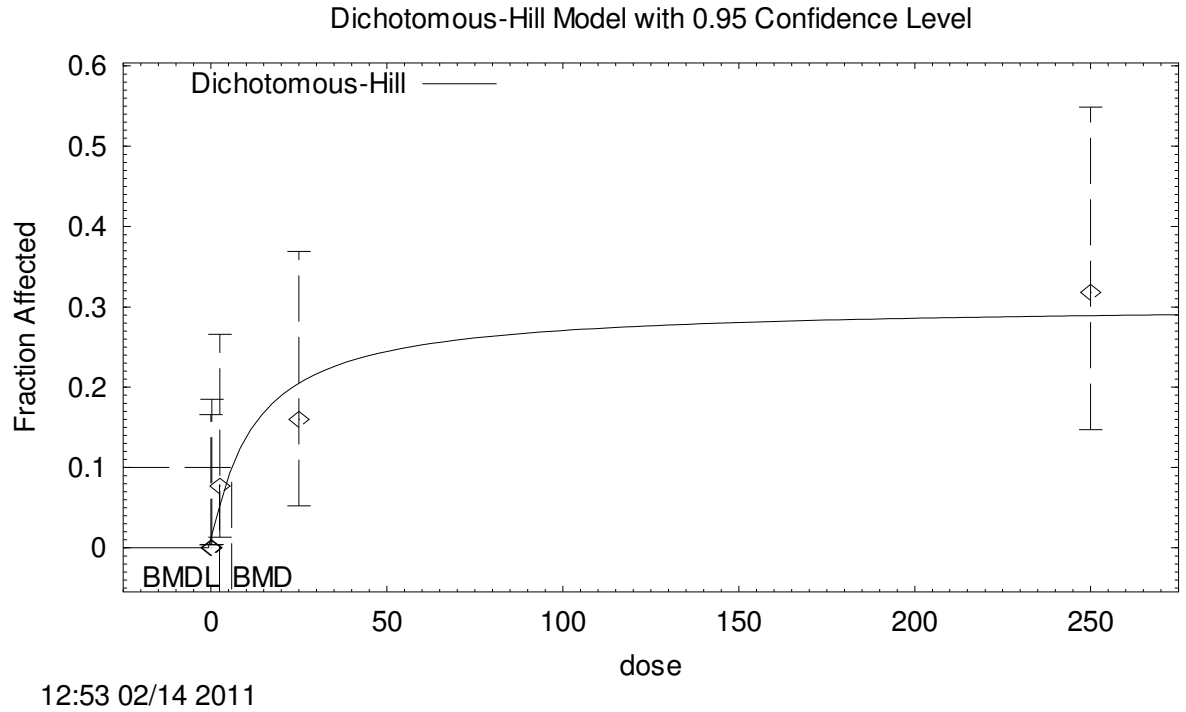
Risk Type = Extra risk

Confidence level = 0.95

BMD = 5.87467

Warning: BMDL computation is at best imprecise for these data

BMDL = 2.39471



Zhu et al. 1987: Liver

Table B-2: Zhu et al. 1987: Spleen (3 months)

Summary Table of BMDS modeling results

Spleen (3 month) (Zhu et al. 1987)						
Model	**Degrees of Freedom**	**X^2 *p*-Value**	**AIC**	**BMD (mg/kg-d)**	**BMDL (mg/kg-d)**	**Notes**
Gamma	3.00	0.52	44.47	43.29	23.61	power bound hit (power = 1)
gamma, unrestricted	3.00	0.94	42.40	11.53	0.88	unrestricted (power = 0.492)
Logistic	3.00	0.37	45.87	109.80	75.41	negative intercept (intercept = -2.996)
log-logistic	3.00	0.56	44.03	31.26	13.20	slope bound hit (slope = 1)
log-logistic, unrestricted	3.00	0.94	42.36	10.30	1.00	unrestricted (slope = 0.596)
log-probit	3.00	0.30	46.26	85.33	45.24	slope bound hit (slope = 1)
log-probit, unrestricted	3.00	0.94	42.30	8.87	1.05	unrestricted (slope = 0.323)
multistage, 4-degree	3.00	0.52	44.47	43.29	23.61	final ß = 0
Probit	3.00	0.38	45.76	99.65	68.31	negative intercept (intercept = -1.684)
Weibull	3.00	0.52	44.47	43.29	23.61	power bound hit (power = 1)
Weibull, unrestricted	3.00	0.94	42.38	10.95	2.38	unrestricted (power =)
quantal linear	3.00	0.52	44.47	43.29	23.61	
dichotomous Hill [a]	3.00	0.79	42.74	9.42	1.47	
dichotomous Hill, unrestricted slope	2.00	0.81	44.36	10.16	1.00	
log-Probit, background dose	3.00	0.49	44.94	54.38	29.20	
log-Probit, background dose, unrestricted	3.00	0.94	42.30	8.87	1.05	
multistage, background dose	2.00	0.32	46.47	43.29	23.61	
probit, background response, unrestricted	2.00	0.22	47.76	99.65	68.31	

[a] Best-fitting model, BMDS output presented in this appendix

Output for selected model: dichotomous Hill

Zhu et al. 1987: Spleen (3 months)

```
 ======================================================================
         Dichotomous Hill Model. (Version: 1.2; Date: 12/11/2009)
         Input Data File:
C:/USEPA/BMDS212/Data/2A_Zhu_1987_Spleen_3_DichHill_dich_hill_spleen3.(d)
         Gnuplot Plotting File:
C:/USEPA/BMDS212/Data/2A_Zhu_1987_Spleen_3_DichHill_dich_hill_spleen3.plt
                                                  Tue Feb 08 13:56:46 2011
 ======================================================================

 [add_notes_here]
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

   The form of the probability function is:

   P[response] = v*g +(v-v*g)/[1+EXP(-intercept-slope*Log(dose))]

        where: 0 <= g < 1, 0 < v <= 1

               v is the maximum probability of response predicted by the model,

               and v*g is the background estimate of that probability.


   Dependent variable = y
   Independent variable = dose
   Slope parameter is restricted as slope >= 1

   Total number of observations = 5
   Total number of records with missing values = 0
   Maximum number of iterations = 250
   Relative Function Convergence has been set to: 1e-008
   Parameter Convergence has been set to: 1e-008



                  Default Initial Parameter Values
                              v =        -9999
                              g =        -9999
                      intercept =     -5.63082
                          slope =            1


           Asymptotic Correlation Matrix of Parameter Estimates

           ( *** The model parameter(s)  -g    -slope
                 have been estimated at a boundary point, or have been specified by the user,
                 and do not appear in the correlation matrix )

                        v    intercept

         v              1        -0.79

 intercept        -0.79            1


                                Parameter Estimates

                                                        95.0% Wald Confidence Interval
      Variable         Estimate        Std. Err. Lower Conf. Limit   Upper Conf. Limit
             v         0.469041         0.205517           0.0662347           0.871846
```

g	0	NA		
intercept	-3.5483	1.25897	-6.01583	-1.08077
slope	1	NA		

NA - Indicates that this parameter has hit a bound
implied by some inequality constraint and thus
has no standard error.

Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-18.9048	5			
Fitted model	-19.3684	2	0.927139	3	0.8189
Reduced model	-26.8563	1	15.9031	4	0.003152

AIC: 42.7367

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.0000	0.000	0.000	14	0.000
0.2500	0.0033	0.047	0.000	14	-0.217
2.5000	0.0315	0.441	1.000	14	0.856
25.0000	0.1962	2.747	2.000	14	-0.503
250.0000	0.4118	5.765	6.000	14	0.128

Chi^2 = 1.05 d.f. = 3 P-value = 0.7893

Benchmark Dose Computation

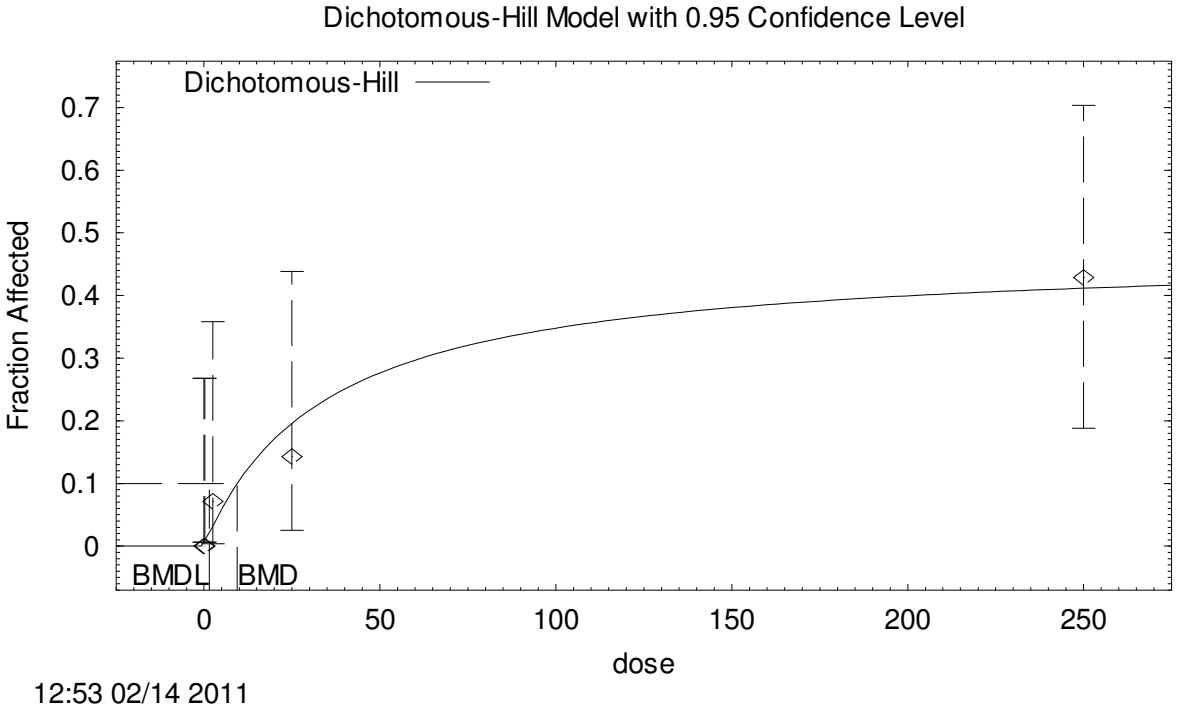
Specified effect = 0.1

Risk Type = Extra risk

Confidence level = 0.95

BMD = 9.41743

BMDL = 1.46712



Zhu et al. 1987: Spleen (3 months)

Table B-3: Zhu et al. 1987: Spleen (6 months)

Summary Table of BMDS modeling results

Spleen (6 month) (Zhu et al. 1987)						
Model	**Degrees of Freedom**	**X^2 *p*-Value**	**AIC**	**BMD (mg/kg-d)**	**BMDL (mg/kg-d)**	**Notes**
gamma	3.00	0.33	63.62	69.11	38.53	power bound hit (power = 1)
gamma, unrestricted	3.00	0.69	61.22	18.73	2.89	unrestricted (power = 0.44)
logistic	3.00	0.32	64.46	137.80	101.60	negative intercept (intercept = -3.258)
log-logistic	3.00	0.33	63.47	58.85	28.26	slope bound hit (slope = 1)
log-logistic, unrestricted	3.00	0.67	61.28	16.71	2.77	unrestricted (slope = 0.503)
log-probit	3.00	0.28	64.84	118.90	72.46	slope bound hit (slope = 1)
log-probit, unrestricted	3.00	0.66	61.30	14.10	2.61	unrestricted (slope = 0.259)
multistage, 4-degree	3.00	0.33	63.62	69.11	38.53	final ß = 0
probit	3.00	0.33	64.38	127.40	92.09	negative intercept (intercept = -1.797)
Weibull	3.00	0.33	63.62	69.11	38.53	power bound hit (power = 1)
quantal linear	3.00	0.33	63.62	69.11	38.53	
dichotomous Hill [a]	3.00	0.35	62.64	10.70	1.47	
dichotomous Hill, unrestricted	3.00	0.67	61.28	16.71	2.75	
logistic, background response, unrestricted	3.00	0.32	64.46	137.80	101.60	
log-Probit, background dose	3.00	0.34	63.93	84.24	48.76	
log-Probit, background dose, unrestricted	3.00	0.66	61.30	14.10	2.61	
multistage, background dose	3.00	0.33	63.62	69.11	38.53	
Weibull, unrestricted	3.00	0.68	61.24	17.77	2.84	unrestricted (power = 0.861)

[a] Best-fitting model, BMDS output presented in this appendix

Output for selected model: dichotomous Hill

Zhu et al. 1987: Spleen (6 months)

```
 ======================================================================
         Dichotomous Hill Model. (Version: 1.2; Date: 12/11/2009)
         Input Data File:
C:/USEPA/BMDS212/Data/2B_Zhu_1987_Spleen_6_DichHill_dich_hill_spleen6.(d)
         Gnuplot Plotting File:
C:/USEPA/BMDS212/Data/2B_Zhu_1987_Spleen_6_DichHill_dich_hill_spleen6.plt
                                                    Tue Feb 08 13:58:31 2011
 ======================================================================

 [add_notes_here]
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

   The form of the probability function is:

   P[response] = v*g +(v-v*g)/[1+EXP(-intercept-slope*Log(dose))]

        where: 0 <= g < 1, 0 < v <= 1

               v is the maximum probability of response predicted by the model,

               and v*g is the background estimate of that probability.


   Dependent variable = y
   Independent variable = dose
   Slope parameter is restricted as slope >= 1

   Total number of observations = 5
   Total number of records with missing values = 0
   Maximum number of iterations = 250
   Relative Function Convergence has been set to: 1e-008
   Parameter Convergence has been set to: 1e-008



                  Default Initial Parameter Values
                              v =        -9999
                              g =        -9999
                      intercept =     -6.10214
                          slope =            1


           Asymptotic Correlation Matrix of Parameter Estimates

           ( *** The model parameter(s)  -g    -slope
                 have been estimated at a boundary point, or have been specified by the user,
                 and do not appear in the correlation matrix )

                       v    intercept

         v             1        -0.84

 intercept        -0.84            1


                                  Parameter Estimates

                                                        95.0% Wald Confidence Interval
```

Variable	Estimate	Std. Err.	Lower Conf. Limit	Upper Conf. Limit
v	0.299454	0.147519	0.0103226	0.588585
g	0	NA		
intercept	-3.06102	1.51231	-6.0251	-0.0969394
slope	1	NA		

NA - Indicates that this parameter has hit a bound
implied by some inequality constraint and thus
has no standard error.

Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-27.781	5			
Fitted model	-29.3188	2	3.07571	3	0.3801
Reduced model	-36.7652	1	17.9685	4	0.001252

AIC: 62.6376

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.0000	0.000	0.000	25	0.000
0.2500	0.0035	0.076	0.000	22	-0.277
2.5000	0.0314	0.816	2.000	26	1.331
25.0000	0.1615	4.038	2.000	25	-1.108
250.0000	0.2759	6.070	7.000	22	0.444

Chi^2 = 3.27 d.f. = 3 P-value = 0.3514

Benchmark Dose Computation

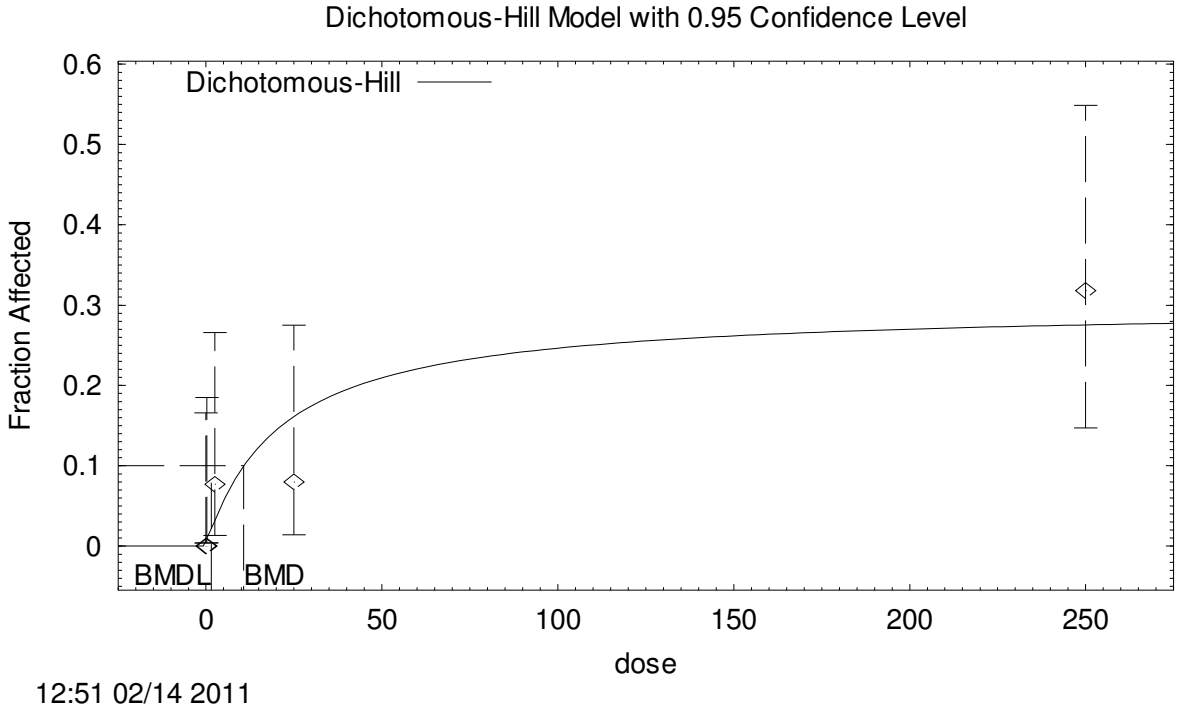
Specified effect = 0.1

Risk Type = Extra risk

Confidence level = 0.95

BMD = 10.7039

BMDL = 1.4671



Zhu et al. 1987: Spleen (6 months)

Table B-4: HLS 2001: White Blood Cells ((historical control)

Model Predictions for Reduction in White Blood Cells (Historical Controls)								
Model	**Homogeneity Variance *p*-value**	**Goodness of fit *p*-value[b]**	**AIC for fitted model**	**BMD_{1sd} ln(dose+1) mg/kg-d**	**BMD1sd mg/kg-d**	**$BMDL_{1sd}$ ln(dose+1) mg/kg-d**	**BMDL1sd mg/kg-d**	**Notes**
Exponential (M4) (nonconstant variance) [a]	0.017	0.161	111.58	3.91	48.88	1.88	5.54	Lowest BMDL
Exponential (M2) (nonconstant variance)	0.017	0.161	111.58	3.91	48.88	2.28	8.78	
Linear (nonconstant variance)	**0.017**	**0.161**	**111.58**	**4.31**	73.13	**2.84**	16.12	

[a] Best-fitting model, BMDS output presented in this appendix

[b] Values <0.10 fail to meet conventional goodness-of-fit criteria
AIC = Akaike's Information Criteria; BMD = benchmark dose; BMDL lower confidence limit (95%) on the benchmark dose

Output for selected model: exponential (M4)

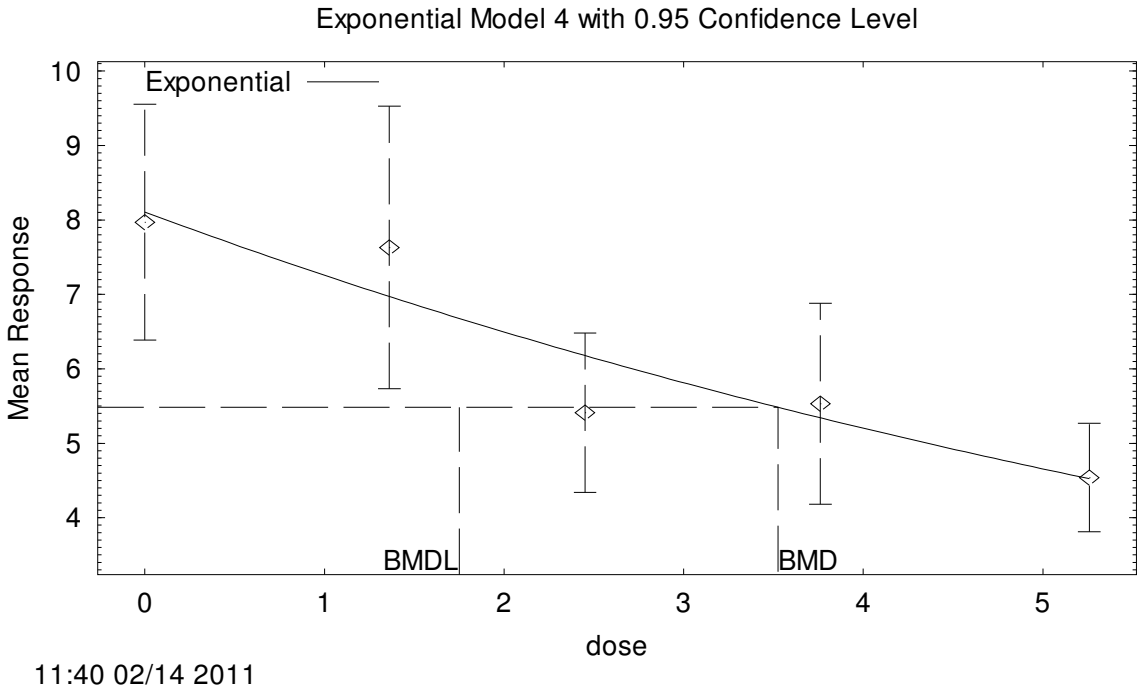
HLS 2001: White Blood Cells

```
 ================================================================
         Exponential Model. (Version: 1.7;  Date: 12/10/2009)
         Input Data File: C:/USEPA/BMDS212/Test/HLS_2001_WBC_Exp_BMR2.(d)
         Gnuplot Plotting File:
                                                Sun Feb 13 21:14:37 2011
 ================================================================

 HLS 2001
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

   The form of the response function by Model:
      Model 2:     Y[dose] = a * exp{sign * b * dose}
      Model 3:     Y[dose] = a * exp{sign * (b * dose)^d}
      Model 4:     Y[dose] = a * [c-(c-1) * exp{-b * dose}]
      Model 5:     Y[dose] = a * [c-(c-1) * exp{-(b * dose)^d}]

    Note: Y[dose] is the median response for exposure = dose;
          sign = +1 for increasing trend in data;
          sign = -1 for decreasing trend.

      Model 2 is nested within Models 3 and 4.
```

```
   Model 3 is nested within Model 5.
   Model 4 is nested within Model 5.


Dependent variable = WBC
Independent variable = alt_dose
Data are assumed to be distributed: normally
Variance Model: exp(lnalpha +rho *ln(Y[dose]))
The variance is to be modeled as Var(i) = exp(lalpha + log(mean(i)) * rho)

Total number of dose groups = 5
Total number of records with missing values = 0
Maximum number of iterations = 250
Relative Function Convergence has been set to: 1e-008
Parameter Convergence has been set to: 1e-008

MLE solution provided: Exact


              Initial Parameter Values

              Variable          Model 4
              --------          --------
                lnalpha            -4.88402
                    rho             3.34041
                      a              8.3685
                      b            0.140286
                      c            0.108502
                      d                   1



                Parameter Estimates

               Variable          Model 4
               --------          -------
                lnalpha           -4.84106
                    rho            3.31339
                      a            8.10018
                      b           0.110604
                      c                  0
                      d                  1


        Table of Stats From Input Data

  Dose      N         Obs Mean     Obs Std Dev
  -----    ---       ----------   -------------
      0     10         7.97        2.626
  1.361     10         7.63        2.653
  2.451      9         5.41        1.392
  3.761      9         5.53        1.756
  5.258     10         4.54        1.019


              Estimated Values of Interest

   Dose      Est Mean      Est Std     Scaled Residual
 ------    ----------    ---------    ----------------
      0           8.1        2.844          -0.1448
  1.361         6.968        2.216           0.9444
  2.451         6.177        1.815           -1.268
  3.761         5.343        1.427            0.392
  5.258         4.528        1.085          0.03437


Other models for which likelihoods are calculated:

  Model A1:        Yij = Mu(i) + e(ij)
```

```
            Var{e(ij)} = Sigma^2

  Model A2:        Yij = Mu(i) + e(ij)
            Var{e(ij)} = Sigma(i)^2

  Model A3:        Yij = Mu(i) + e(ij)
            Var{e(ij)} = exp(lalpha + log(mean(i)) * rho)

  Model  R:        Yij = Mu + e(i)
            Var{e(ij)} = Sigma^2


                           Likelihoods of Interest

                 Model      Log(likelihood)      DF         AIC
                -------    -----------------    ----   ------------
                    A1       -55.03553            6      122.0711
                    A2       -49.00331           10      118.0066
                    A3        -49.2142            7      112.4284
                     R       -64.89649            2       133.793
                     4       -51.79076            4      111.5815

Additive constant for all log-likelihoods =     -44.11. This constant added to the
above values gives the log-likelihood including the term that does not
depend on the model parameters.


                             Explanation of Tests

Test 1:  Does response and/or variances differ among Dose levels? (A2 vs. R)
Test 2:  Are Variances Homogeneous? (A2 vs. A1)
Test 3:  Are variances adequately modeled? (A2 vs. A3)

Test 6a: Does Model 4 fit the data? (A3 vs 4)


                         Tests of Interest

  Test          -2*log(Likelihood Ratio)       D. F. p-value
--------        ------------------------      ------     --------------
  Test 1                         31.79           8           0.0001017
  Test 2                         12.06           4             0.01688
  Test 3                        0.4218           3              0.9357
 Test 6a                         5.153           3              0.1609


  The p-value for Test 1 is less than .05. There appears to be a
  difference between response and/or variances among the dose
  levels, it seems appropriate to model the data.

  The p-value for Test 2 is less than .1. A non-homogeneous
  variance model appears to be appropriate.

  The p-value for Test 3 is greater than .1. The modeled
  variance appears to be appropriate here.

  The p-value for Test 6a is greater than .1. Model 4 seems
  to adequately describe the data.


Benchmark Dose Computations:

  Specified Effect = 1.000000

         Risk Type = Estimated standard deviations from control

  Confidence Level = 0.950000

               BMD =      3.90954
```

```
BMDL =      1.87853
```



HLS 2001: White Blood Cells (historical controls)

Table B-5 of BMDS modeling results (concurrent control)

Model Predictions for Reduction in White Blood Cells (Concurrent Control)								
Model	**Homogeneity Variance *p*-value**	**Goodness of fit *p*-value[b]**	**AIC for fitted model**	**BMD_{1sd} ln(dose+1) mg/kg-d**	**BMD1sd mg/kg-d**	**$BMDL_{1sd}$ ln(dose+1) mg/kg-d**	**BMDL1sd mg/kg-d**	**Notes**
Exponential (M4) (nonconstant variance) [a]	0.036	0.130	109.18	3.53	32.96	1.75	4.75	Lowest BMDL
Exponential (M2) (nonconstant variance)	0.036	0.130	109.18	3.53	32.96	2.08	6.99	
Linear (nonconstant variance)	**0.036**	**0.136**	**109.06**	**3.96**	51.23	**2.61**	12.66	**Lowest AIC**

[a] Best-fitting model, BMDS output presented in this appendix

[b] Values <0.10 fail to meet conventional goodness-of-fit criteria
AIC = Akaike's Information Criteria; BMD = benchmark dose; BMDL lower confidence limit (95%) on the benchmark dose

Output for model presented: exponential (M4)

HLS 2001: WBC (Concurrent Control)

```
 ================================================================
         Exponential Model. (Version: 1.7;  Date: 12/10/2009)
         Input Data File: C:/USEPA/BMDS212/Test/HLS_2001_WBC_con_Exp_BMR2.(d)
         Gnuplot Plotting File:
                                                 Sun Feb 13 21:29:06 2011
 ================================================================

 HLS 2001
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

   The form of the response function by Model:
      Model 2:     Y[dose] = a * exp{sign * b * dose}
      Model 3:     Y[dose] = a * exp{sign * (b * dose)^d}
      Model 4:     Y[dose] = a * [c-(c-1) * exp{-b * dose}]
      Model 5:     Y[dose] = a * [c-(c-1) * exp{-(b * dose)^d}]

    Note: Y[dose] is the median response for exposure = dose;
          sign = +1 for increasing trend in data;
          sign = -1 for decreasing trend.

      Model 2 is nested within Models 3 and 4.
      Model 3 is nested within Model 5.
```

Model 4 is nested within Model 5.

Dependent variable = WBC
Independent variable = alt_dose
Data are assumed to be distributed: normally
Variance Model: exp(lnalpha +rho *ln(Y[dose]))
The variance is to be modeled as Var(i) = exp(lalpha + log(mean(i)) * rho)

Total number of dose groups = 5
Total number of records with missing values = 0
Maximum number of iterations = 250
Relative Function Convergence has been set to: 1e-008
Parameter Convergence has been set to: 1e-008

MLE solution provided: Exact

Initial Parameter Values

Variable	Model 4
lnalpha	-4.23146
rho	2.9407
a	8.3685
b	0.129448
c	0.0542511
d	1

Parameter Estimates

Variable	Model 4
lnalpha	-4.16406
rho	2.91156
a	8.10768
b	0.110916
c	0
d	1

Table of Stats From Input Data

Dose	N	Obs Mean	Obs Std Dev
0	10	7.97	2.213
1.361	10	7.63	2.653
2.451	9	5.41	1.392
3.761	9	5.53	1.756
5.258	10	4.54	1.019

Estimated Values of Interest

Dose	Est Mean	Est Std	Scaled Residual
0	8.108	2.624	-0.1659
1.361	6.972	2.106	0.9884
2.451	6.178	1.766	-1.304
3.761	5.342	1.43	0.3942
5.258	4.525	1.123	0.0423

Other models for which likelihoods are calculated:

Model A1: $Yij = Mu(i) + e(ij)$
$Var\{e(ij)\} = Sigma^2$

```
  Model A2:        Yij = Mu(i) + e(ij)
           Var{e(ij)} = Sigma(i)^2

  Model A3:        Yij = Mu(i) + e(ij)
           Var{e(ij)} = exp(lalpha + log(mean(i)) * rho)

  Model  R:        Yij = Mu + e(i)
           Var{e(ij)} = Sigma^2
```

Likelihoods of Interest

Model	Log(likelihood)	DF	AIC
A1	-52.43142	6	116.8628
A2	-47.29218	10	114.5844
A3	-47.75877	7	109.5175
R	-63.20171	2	130.4034
4	-50.58752	4	109.175

Additive constant for all log-likelihoods = -44.11. This constant added to the above values gives the log-likelihood including the term that does not depend on the model parameters.

Explanation of Tests

Test 1: Does response and/or variances differ among Dose levels? (A2 vs. R)
Test 2: Are Variances Homogeneous? (A2 vs. A1)
Test 3: Are variances adequately modeled? (A2 vs. A3)

Test 6a: Does Model 4 fit the data? (A3 vs 4)

Tests of Interest

Test	-2*log(Likelihood Ratio)	D. F.	p-value
Test 1	31.82	8	0.0001004
Test 2	10.28	4	0.03599
Test 3	0.9332	3	0.8174
Test 6a	5.658	3	0.1295

The p-value for Test 1 is less than .05. There appears to be a difference between response and/or variances among the dose levels, it seems appropriate to model the data.

The p-value for Test 2 is less than .1. A non-homogeneous variance model appears to be appropriate.

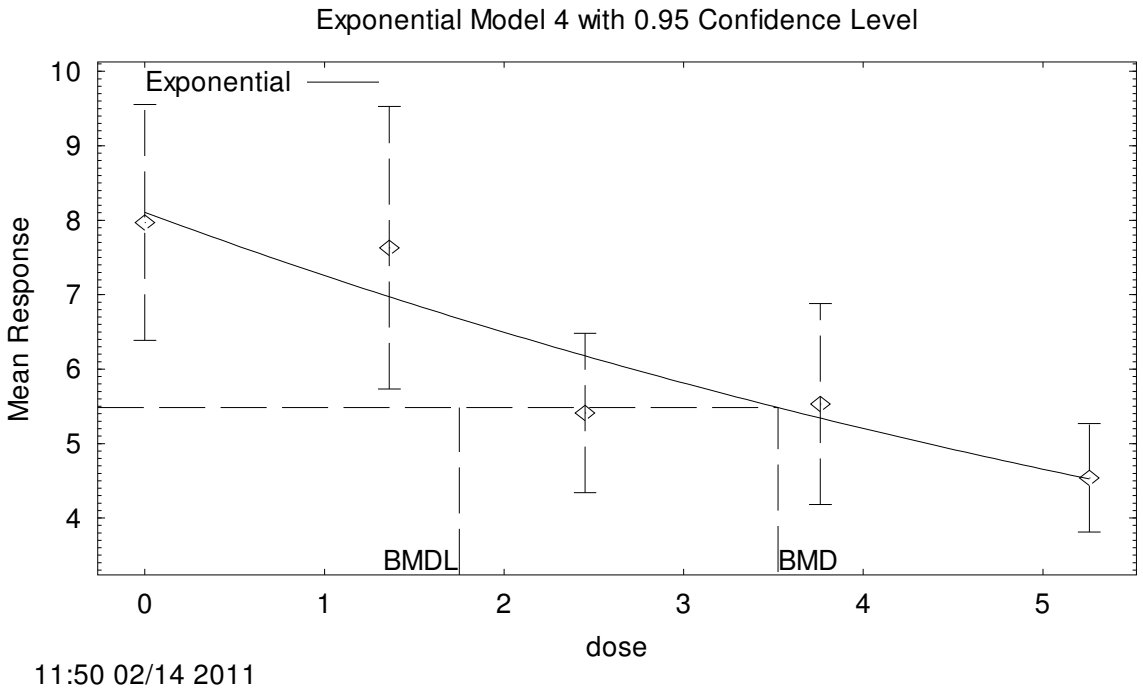
The p-value for Test 3 is greater than .1. The modeled variance appears to be appropriate here.

The p-value for Test 6a is greater than .1. Model 4 seems to adequately describe the data.

Benchmark Dose Computations:

```
  Specified Effect = 1.000000

         Risk Type = Estimated standard deviations from control

  Confidence Level = 0.950000

               BMD =      3.52527
```

BMDL = 1.7499



HLS 2001: WBC (Concurrent Control)

Table B-6: HLS 2001: Lymphocytes (historical control)

Model Predictions for Reduction in Lymphocytes (Historical Control)								
Model	**Homogeneity Variance *p*-value**	**Goodness of fit *p*-value[b]**	**AIC for fitted model**	**BMD_{1sd} ln(dose+1) mg/kg-d**	**BMD1sd mg/kg-d**	**$BMDL_{1sd}$ ln(dose+1) mg/kg-d**	**BMDL1sd mg/kg-d**	**Notes**
Exponential (M4) (nonconstant variance) [a]	**0.023**	**0.168**	**102.46**	**3.86**	46.46	**1.68**	4.38	**Lowest AIC Lowest BMDL**
Exponential (M2) (nonconstant variance)	**0.023**	**0.168**	**102.46**	**3.86**	46.46	**2.19**	7.96	**Lowest AIC**
Linear (nonconstant variance)	0.023	0.158	102.61	4.34	75.55	2.83	15.90	

[a] Best-fitting model, BMDS output presented in this appendix

[b] Values <0.10 fail to meet conventional goodness-of-fit criteria

AIC = Akaike's Information Criteria; BMD = benchmark dose; BMDL lower confidence limit (95%) on the benchmark dose

Output for selected model: exponential (M4)

HLS 2001: Lymphocytes (Historical Control)

```
 ================================================================
         Exponential Model. (Version: 1.7;  Date: 12/10/2009)
         Input Data File: C:/USEPA/BMDS212/Test/HLS_2001_Lymphocytes_Exp_BMR2.(d)
         Gnuplot Plotting File:
                                                  Mon Feb 14 10:49:36 2011
 ================================================================

 HLS 2001
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

   The form of the response function by Model:
      Model 2:     Y[dose] = a * exp{sign * b * dose}
      Model 3:     Y[dose] = a * exp{sign * (b * dose)^d}
      Model 4:     Y[dose] = a * [c-(c-1) * exp{-b * dose}]
      Model 5:     Y[dose] = a * [c-(c-1) * exp{-(b * dose)^d}]

    Note: Y[dose] is the median response for exposure = dose;
          sign = +1 for increasing trend in data;
          sign = -1 for decreasing trend.
```

```
   Model 2 is nested within Models 3 and 4.
   Model 3 is nested within Model 5.
   Model 4 is nested within Model 5.


Dependent variable = Lymph
Independent variable = alt_dose
Data are assumed to be distributed: normally
Variance Model: exp(lnalpha +rho *ln(Y[dose]))
The variance is to be modeled as Var(i) = exp(lalpha + log(mean(i)) * rho)

Total number of dose groups = 5
Total number of records with missing values = 0
Maximum number of iterations = 250
Relative Function Convergence has been set to: 1e-008
Parameter Convergence has been set to: 1e-008

MLE solution provided: Exact


               Initial Parameter Values

               Variable          Model 4
               --------          --------
                 lnalpha            -3.80574
                     rho             2.92924
                       a               7.329
                       b            0.208881
                       c            0.254469
                       d                   1


                  Parameter Estimates

                Variable          Model 4
                --------          -------
                 lnalpha           -3.90323
                     rho            2.98476
                       a             6.9219
                       b           0.118982
                       c                  0
                       d                  1


        Table of Stats From Input Data

  Dose      N         Obs Mean     Obs Std Dev
  -----    ---       ----------   -------------
      0     10         6.98         2.29
  1.361     10         6.36        2.452
  2.451      9         4.39        1.308
  3.761      9         4.63        1.564
  5.258     10         3.73        0.941


               Estimated Values of Interest

   Dose      Est Mean      Est Std     Scaled Residual
 ------    ----------    ---------    ----------------
      0         6.922        2.549          0.07208
  1.361         5.887        2.002           0.7471
  2.451         5.171        1.649            -1.42
  3.761         4.425        1.307           0.4715
  5.258         3.703        1.002          0.08592


Other models for which likelihoods are calculated:
```

```
  Model A1:        Yij = Mu(i) + e(ij)
           Var{e(ij)} = Sigma^2

  Model A2:        Yij = Mu(i) + e(ij)
           Var{e(ij)} = Sigma(i)^2

  Model A3:        Yij = Mu(i) + e(ij)
           Var{e(ij)} = exp(lalpha + log(mean(i)) * rho)

  Model  R:        Yij = Mu + e(i)
           Var{e(ij)} = Sigma^2
```

Likelihoods of Interest

Model	Log(likelihood)	DF	AIC
A1	-50.12088	6	112.2418
A2	-44.44769	10	108.8954
A3	-44.70446	7	103.4089
R	-60.31932	2	124.6386
4	-47.2319	4	102.4638

Additive constant for all log-likelihoods = -44.11. This constant added to the above values gives the log-likelihood including the term that does not depend on the model parameters.

Explanation of Tests

Test 1: Does response and/or variances differ among Dose levels? (A2 vs. R)
Test 2: Are Variances Homogeneous? (A2 vs. A1)
Test 3: Are variances adequately modeled? (A2 vs. A3)

Test 6a: Does Model 4 fit the data? (A3 vs 4)

Tests of Interest

Test	-2*log(Likelihood Ratio)	D. F.	p-value
Test 1	31.74	8	0.0001035
Test 2	11.35	4	0.02294
Test 3	0.5135	3	0.9159
Test 6a	5.055	3	0.1678

The p-value for Test 1 is less than .05. There appears to be a difference between response and/or variances among the dose levels, it seems appropriate to model the data.

The p-value for Test 2 is less than .1. A non-homogeneous variance model appears to be appropriate.

The p-value for Test 3 is greater than .1. The modeled variance appears to be appropriate here.

The p-value for Test 6a is greater than .1. Model 4 seems to adequately describe the data.

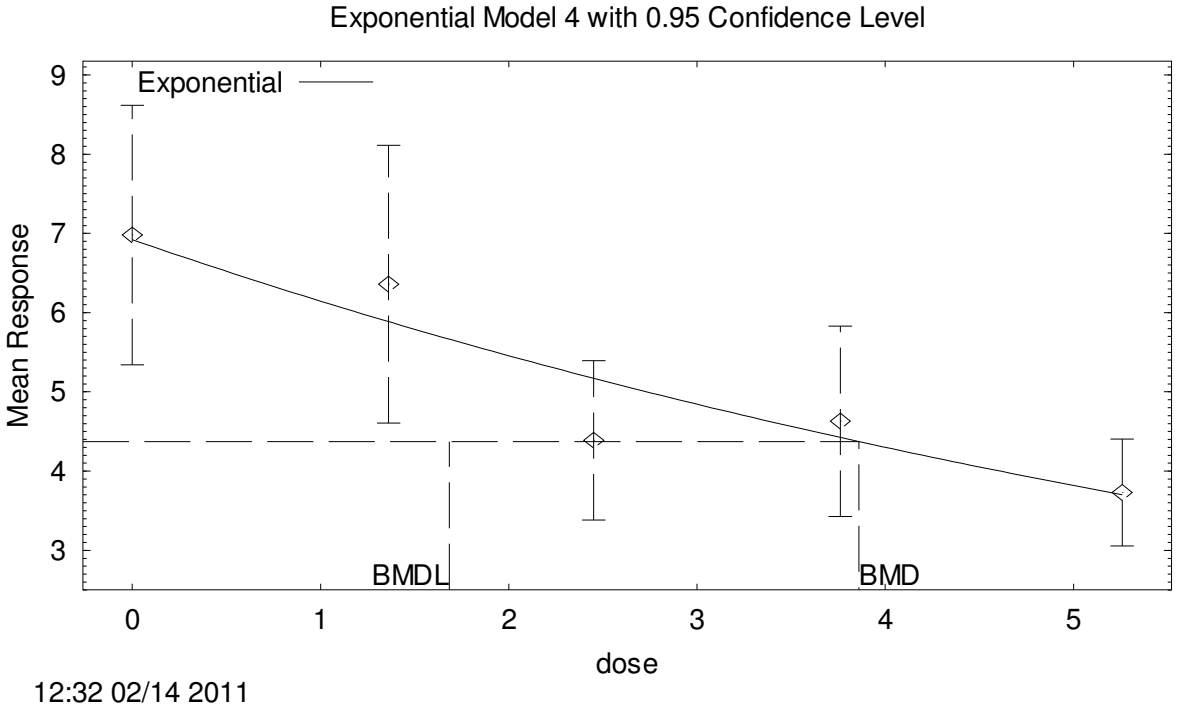
Benchmark Dose Computations:

Specified Effect = 1.000000

Risk Type = Estimated standard deviations from control

Confidence Level = 0.950000

```
BMD =       3.85985

BMDL =      1.68317
```



HLS 2001: Lymphocytes

HLS 2001: Lymphocytes (Concurrent Control)

TableB-7 of BMDS modeling results (Concurrent Control)

Model Predictions for Reduction in Lymphocytes (Concurrent Control)								
Model	**Homogeneity Variance *p*-value**	**Goodness of fit *p*-value[b]**	**AIC for fitted model**	**BMD_{1sd} ln(dose+1) mg/kg-d**	**BMD1sd mg/kg-d**	**$BMDL_{1sd}$ ln(dose+1) mg/kg-d**	**BMDL1sd mg/kg-d**	**Notes**
Exponential (M4) (nonconstant variance) [a]	**0.031**	**0.158**	**101.55**	**3.70**	39.47	**1.63**	4.12	**Lowest AIC Lowest BMDL**
Exponential (M2) (nonconstant variance)	**0.031**	**0.158**	**101.55**	**3.70**	39.47	**2.11**	7.26	**Lowest AIC**
Linear (nonconstant variance)	0.031	0.151	101.65	4.20	65.48	2.74	14.45	

[a] Best-fitting model, BMDS output presented in this appendix

[b] Values <0.10 fail to meet conventional goodness-of-fit criteria
AIC = Akaike's Information Criteria; BMD = benchmark dose; BMDL lower confidence limit (95%) on the benchmark dose

```
 ======================================================================
         Exponential Model. (Version: 1.7;  Date: 12/10/2009)
         Input Data File: C:/USEPA/BMDS212/Test/HLS_2001_Lymphocytes_con_Exp_BMR2.(d)
         Gnuplot Plotting File:
                                                  Mon Feb 14 11:04:45 2011
 ======================================================================

 HLS 2001
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

   The form of the response function by Model:
      Model 2:     Y[dose] = a * exp{sign * b * dose}
      Model 3:     Y[dose] = a * exp{sign * (b * dose)^d}
      Model 4:     Y[dose] = a * [c-(c-1) * exp{-b * dose}]
      Model 5:     Y[dose] = a * [c-(c-1) * exp{-(b * dose)^d}]

    Note: Y[dose] is the median response for exposure = dose;
          sign = +1 for increasing trend in data;
          sign = -1 for decreasing trend.

      Model 2 is nested within Models 3 and 4.
      Model 3 is nested within Model 5.
      Model 4 is nested within Model 5.


   Dependent variable = Lymph
   Independent variable = alt_dose
```

Data are assumed to be distributed: normally
Variance Model: exp(lnalpha +rho *ln(Y[dose]))
The variance is to be modeled as Var(i) = exp(lalpha + log(mean(i)) * rho)

Total number of dose groups = 5
Total number of records with missing values = 0
Maximum number of iterations = 250
Relative Function Convergence has been set to: 1e-008
Parameter Convergence has been set to: 1e-008

MLE solution provided: Exact

Initial Parameter Values

Variable	Model 4
lnalpha	-3.58873
rho	2.77965
a	7.329
b	0.208881
c	0.254469
d	1

Parameter Estimates

Variable	Model 4
lnalpha	-3.68366
rho	2.8384
a	6.92764
b	0.119266
c	0
d	1

Table of Stats From Input Data

Dose	N	Obs Mean	Obs Std Dev
0	10	6.98	2.146
1.361	10	6.36	2.452
2.451	9	4.39	1.308
3.761	9	4.63	1.564
5.258	10	3.73	0.941

Estimated Values of Interest

Dose	Est Mean	Est Std	Scaled Residual
0	6.928	2.472	0.06698
1.361	5.89	1.963	0.7575
2.451	5.172	1.633	-1.436
3.761	4.424	1.308	0.4736
5.258	3.7	1.015	0.09245

Other models for which likelihoods are calculated:

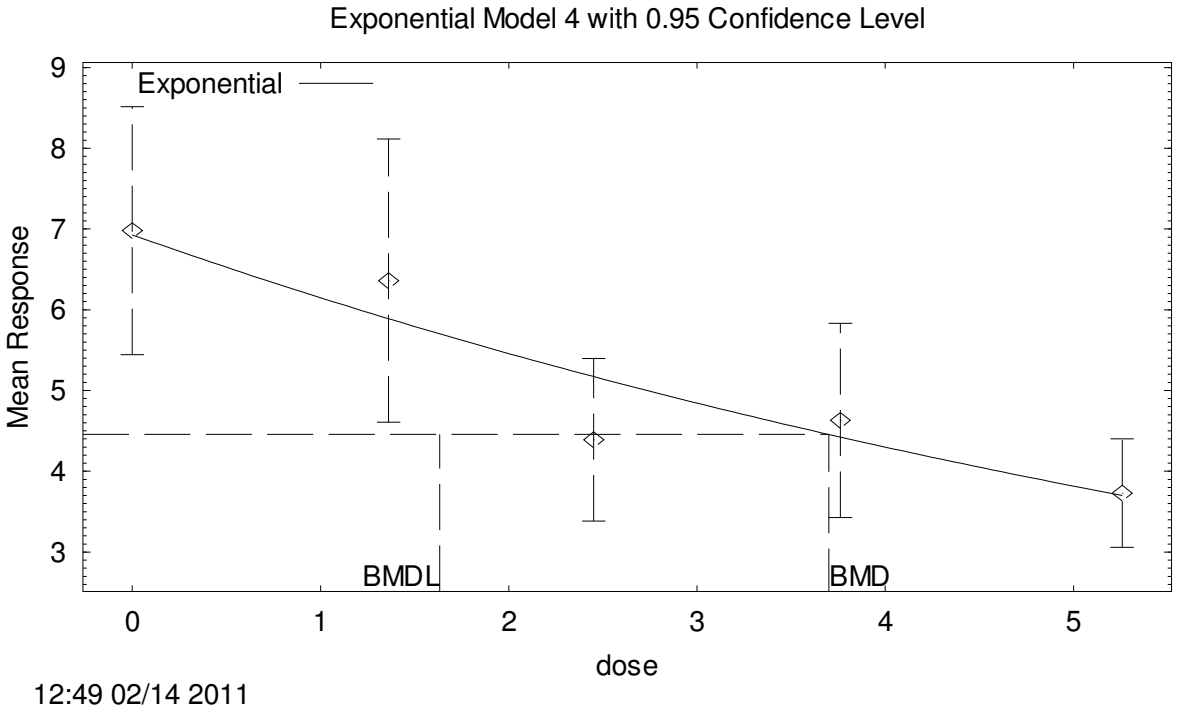
Model A1: Yij = Mu(i) + e(ij)
Var{e(ij)} = Sigma^2

Model A2: Yij = Mu(i) + e(ij)
Var{e(ij)} = Sigma(i)^2

Model A3: Yij = Mu(i) + e(ij)

```
            Var{e(ij)} = exp(lalpha + log(mean(i)) * rho)

  Model  R:        Yij = Mu + e(i)
            Var{e(ij)} = Sigma^2


                          Likelihoods of Interest

                 Model      Log(likelihood)      DF         AIC
                -------    -----------------    ----   ------------
                    A1       -49.13278           6      110.2656
                    A2       -43.79823          10      107.5965
                    A3       -44.17752           7       102.355
                     R        -59.6779           2      123.3558
                     4       -46.77582           4      101.5516


Additive constant for all log-likelihoods =     -44.11. This constant added to the
above values gives the log-likelihood including the term that does not
depend on the model parameters.


                             Explanation of Tests

Test 1:  Does response and/or variances differ among Dose levels? (A2 vs. R)
Test 2:  Are Variances Homogeneous? (A2 vs. A1)
Test 3:  Are variances adequately modeled? (A2 vs. A3)

Test 6a: Does Model 4 fit the data? (A3 vs 4)


                        Tests of Interest

  Test          -2*log(Likelihood Ratio)       D. F. p-value
--------        ------------------------      ------     --------------
  Test 1                      31.76             8           0.0001029
  Test 2                      10.67             4             0.03055
  Test 3                     0.7586             3              0.8593
 Test 6a                      5.197             3               0.158


  The p-value for Test 1 is less than .05. There appears to be a
  difference between response and/or variances among the dose
  levels, it seems appropriate to model the data.

  The p-value for Test 2 is less than .1. A non-homogeneous
  variance model appears to be appropriate.

  The p-value for Test 3 is greater than .1. The modeled
  variance appears to be appropriate here.

  The p-value for Test 6a is greater than .1. Model 4 seems
  to adequately describe the data.


Benchmark Dose Computations:

  Specified Effect = 1.000000

         Risk Type = Estimated standard deviations from control

  Confidence Level = 0.950000

               BMD =      3.70068
```

BMDL = 1.6333



HLS 2001: Lymphocytes (Concurrent Control)

Table B-8:OECD 2004: Live Pups Day 4

Summary Table of BMDS modeling results

Survival (OECD 2004)						
Model [a]	**Degrees of Freedom**	**X^2 *p*-Value**	**AIC**	**BMD (mg/kg-d)**	**BMDL (mg/kg-d)**	**Notes**
exponential (M3) [b]	1.00	0.71	114.86	239.40	161.20	Lowest AIC
polynomial, 3-degree	1.00	0.62	114.97	255.80	146.50	
power	1.00	0.66	114.92	248.20	153.10	

[a] Non-constant variance model selected (p = <0.0001)

[b] Best-fitting model, BMDS output presented in this appendix

Output for selected model: exponential (M3)

OECD 2004: Live Pups Day 4

```
 ======================================================================
         Exponential Model. (Version: 1.7;  Date: 12/10/2009)
         Input Data File: C:/USEPA/BMDS212/Data/OECD 2004_pups_alive_day4_Exp_birth.(d)
         Gnuplot Plotting File:
                                                  Tue Feb 08 14:03:40 2011
 ======================================================================

 OECD 2004
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

   The form of the response function by Model:
      Model 2:     Y[dose] = a * exp{sign * b * dose}
      Model 3:     Y[dose] = a * exp{sign * (b * dose)^d}
      Model 4:     Y[dose] = a * [c-(c-1) * exp{-b * dose}]
      Model 5:     Y[dose] = a * [c-(c-1) * exp{-(b * dose)^d}]

    Note: Y[dose] is the median response for exposure = dose;
          sign = +1 for increasing trend in data;
          sign = -1 for decreasing trend.

      Model 2 is nested within Models 3 and 4.
      Model 3 is nested within Model 5.
      Model 4 is nested within Model 5.


   Dependent variable = Obs_Mean
   Independent variable = dose
   Data are assumed to be distributed: normally
   Variance Model: exp(lnalpha +rho *ln(Y[dose]))
   The variance is to be modeled as Var(i) = exp(lalpha + log(mean(i)) * rho)

   Total number of dose groups = 4
```

Total number of records with missing values = 0
Maximum number of iterations = 250
Relative Function Convergence has been set to: 1e-008
Parameter Convergence has been set to: 1e-008

MLE solution provided: Exact

Initial Parameter Values

Variable	Model 3
lnalpha	5.99242
rho	-1.86471
a	3.58254
b	-8.246e-007
c	0
d	2

Parameter Estimates

Variable	Model 3
lnalpha	5.58675
rho	-1.7118
a	14.902
b	0.00163543
c	0
d	2.30684

Table of Stats From Input Data

Dose	N	Obs Mean	Obs Std Dev
0	11	14.8	1.8
60	12	15	1.9
200	10	13.7	1.3
700	9	4	5.6

Estimated Values of Interest

Dose	Est Mean	Est Std	Scaled Residual
0	14.9	1.618	-0.2091
60	14.83	1.625	0.3587
200	13.81	1.727	-0.2059
700	3.802	5.209	0.1143

Other models for which likelihoods are calculated:

Model A1: Yij = Mu(i) + e(ij)
Var{e(ij)} = Sigma^2

Model A2: Yij = Mu(i) + e(ij)
Var{e(ij)} = Sigma(i)^2

Model A3: Yij = Mu(i) + e(ij)
Var{e(ij)} = exp(lalpha + log(mean(i)) * rho)

Model R: Yij = Mu + e(i)
Var{e(ij)} = Sigma^2

Likelihoods of Interest

Model	Log(likelihood)	DF	AIC
A1	-64.80532	5	139.6106
A2	-51.19334	8	118.3867
A3	-52.36184	6	116.7237
R	-90.21303	2	184.4261
3	-52.43031	5	114.8606

Additive constant for all log-likelihoods = -38.6. This constant added to the above values gives the log-likelihood including the term that does not depend on the model parameters.

Explanation of Tests

Test 1: Does response and/or variances differ among Dose levels? (A2 vs. R)
Test 2: Are Variances Homogeneous? (A2 vs. A1)
Test 3: Are variances adequately modeled? (A2 vs. A3)

Test 5a: Does Model 3 fit the data? (A3 vs 3)

Tests of Interest

Test	-2*log(Likelihood Ratio)	D. F.	p-value
Test 1	78.04	6	< 0.0001
Test 2	27.22	3	< 0.0001
Test 3	2.337	2	0.3108
Test 5a	0.1369	1	0.7113

The p-value for Test 1 is less than .05. There appears to be a difference between response and/or variances among the dose levels, it seems appropriate to model the data.

The p-value for Test 2 is less than .1. A non-homogeneous variance model appears to be appropriate.

The p-value for Test 3 is greater than .1. The modeled variance appears to be appropriate here.

The p-value for Test 5a is greater than .1. Model 3 seems to adequately describe the data.

Benchmark Dose Computations:

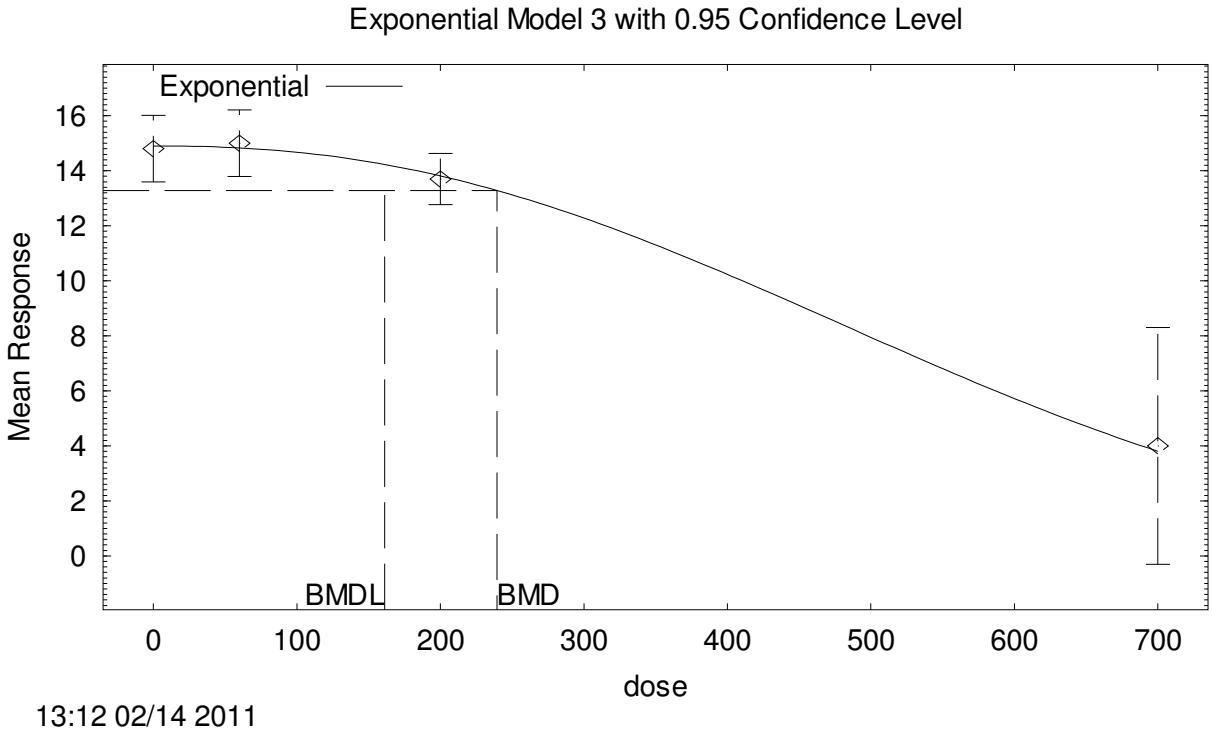
Specified Effect = 1.000000

Risk Type = Estimated standard deviations from control

Confidence Level = 0.950000

BMD = 239.373

BMDL = 161.176



OECD 2004: Live Pups Day 4

Table B-9: OECD 2004: Birth index

Summary Table of BMDS modeling results

Birth Index (OECD 2004)						
Model [a]	**Degrees of Freedom**	**X^2 *p*-Value**	**AIC**	**BMD (mg/kg-d)**	**BMDL (mg/kg-d)**	**Notes**
exponential (M2)	2.00	0.18	229.80	137.70	88.48	
exponential (M3) [b]	1.00	0.58	228.70	214.90	119.70	Lowest AIC
linear	2.00	0.28	228.97	142.60	95.69	
polynomial, 3-degree	1.00	0.46	228.95	219.90	113.70	
power	1.00	0.55	228.76	216.70	117.40	

[a] Non-constant variance model selected (p = <0.0001)

[b] Best-fitting model, BMDS output presented in this appendix

Output for selected model: exponential (M3)

OECD 2004: Birth index

```
 ======================================================================
         Exponential Model. (Version: 1.7;  Date: 12/10/2009)
         Input Data File: C:/USEPA/BMDS212/Data/OECD 2004_birth_index_Exp_birth.(d)
         Gnuplot Plotting File:
                                                  Tue Feb 08 14:04:30 2011
 ======================================================================

 OECD 2004
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

   The form of the response function by Model:
      Model 2:     Y[dose] = a * exp{sign * b * dose}
      Model 3:     Y[dose] = a * exp{sign * (b * dose)^d}
      Model 4:     Y[dose] = a * [c-(c-1) * exp{-b * dose}]
      Model 5:     Y[dose] = a * [c-(c-1) * exp{-(b * dose)^d}]

    Note: Y[dose] is the median response for exposure = dose;
          sign = +1 for increasing trend in data;
          sign = -1 for decreasing trend.

      Model 2 is nested within Models 3 and 4.
      Model 3 is nested within Model 5.
      Model 4 is nested within Model 5.


   Dependent variable = Obs_Mean
```

```
Independent variable = dose
Data are assumed to be distributed: normally
Variance Model: exp(lnalpha +rho *ln(Y[dose]))
The variance is to be modeled as Var(i) = exp(lalpha + log(mean(i)) * rho)

Total number of dose groups = 4
Total number of records with missing values = 0
Maximum number of iterations = 250
Relative Function Convergence has been set to: 1e-008
Parameter Convergence has been set to: 1e-008

MLE solution provided: Exact
```

Initial Parameter Values

Variable	Model 3
lnalpha	52.9161
rho	-10.8897
a	80.128
b	0.000438051
c	0
d	1

Parameter Estimates

Variable	Model 3
lnalpha	46.0602
rho	-9.38104
a	96.135
b	0.000708097
c	0
d	1.5534

Table of Stats From Input Data

Dose	N	Obs Mean	Obs Std Dev
0	11	96.3	6.5
60	12	95.8	4.8
200	10	90.5	5.1
700	10	71.6	26.2

Estimated Values of Interest

Dose	Est Mean	Est Std	Scaled Residual
0	96.13	5.025	0.1089
60	95.43	5.202	0.2488
200	91.63	6.294	-0.5669
700	68.69	24.31	0.3783

```
Other models for which likelihoods are calculated:

  Model A1:        Yij = Mu(i) + e(ij)
           Var{e(ij)} = Sigma^2

  Model A2:        Yij = Mu(i) + e(ij)
           Var{e(ij)} = Sigma(i)^2

  Model A3:        Yij = Mu(i) + e(ij)
           Var{e(ij)} = exp(lalpha + log(mean(i)) * rho)
```

```
  Model  R:        Yij = Mu + e(i)
            Var{e(ij)} = Sigma^2
```

Likelihoods of Interest

Model	Log(likelihood)	DF	AIC
A1	-131.2566	5	272.5131
A2	-107.7633	8	231.5267
A3	-109.2007	6	230.4013
R	-141.2441	2	286.4883
3	-109.3519	5	228.7037

Additive constant for all log-likelihoods = -39.51. This constant added to the above values gives the log-likelihood including the term that does not depend on the model parameters.

Explanation of Tests

Test 1: Does response and/or variances differ among Dose levels? (A2 vs. R)
Test 2: Are Variances Homogeneous? (A2 vs. A1)
Test 3: Are variances adequately modeled? (A2 vs. A3)

Test 5a: Does Model 3 fit the data? (A3 vs 3)

Tests of Interest

Test	-2*log(Likelihood Ratio)	D. F.	p-value
Test 1	66.96	6	< 0.0001
Test 2	46.99	3	< 0.0001
Test 3	2.875	2	0.2376
Test 5a	0.3024	1	0.5824

The p-value for Test 1 is less than .05. There appears to be a difference between response and/or variances among the dose levels, it seems appropriate to model the data.

The p-value for Test 2 is less than .1. A non-homogeneous variance model appears to be appropriate.

The p-value for Test 3 is greater than .1. The modeled variance appears to be appropriate here.

The p-value for Test 5a is greater than .1. Model 3 seems to adequately describe the data.

Benchmark Dose Computations:

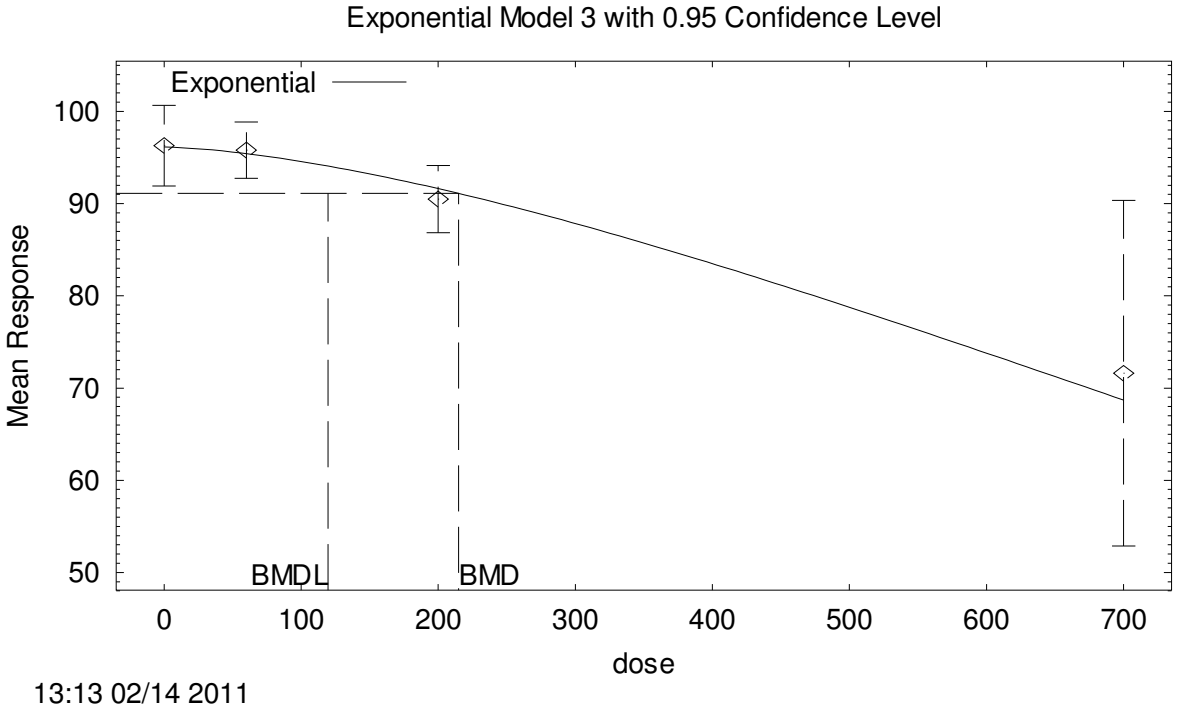
Specified Effect = 1.000000

Risk Type = Estimated standard deviations from control

Confidence Level = 0.950000

BMD = 214.899

BMDL = 119.71



OECD 2004: Birth index

Sulfolane
CASRN 126-33-0
September 6, 2011

ToxStrategies of Austin (August 18, 2010) and URS of Houston (January 31, 2011) submitted proposed RfDs and/or RfCs for the March 2011 TRRP toxicity factor update. The Toxicology Division (TD) reviewed that information and provided toxicity factors in a March 9, 2011 document. This document updates the March 9, 2011 toxicity factor documentation with a slightly revised benchmark dose (BMD) and an animal-to-human extrapolation procedure reflective of the June 2011 proposed *Guidelines to Develop Effects Screening Levels, Reference Values, and Unit Risk Factors (RG-442)* by the Texas Commission on Environmental Quality (TCEQ). These changes increase the RfD by a factor of 3.5, primarily due to the updated animal-to-human extrapolation procedure which received favorable external expert peer review as part of the proposed RG-442 guidelines.

ToxStrategies initially proposed an RfD of 1.2E-02 mg/kg-day based on a $BMDL_{1SD}$ of 15.1 mg/kg-day for reduced white blood cells (WBCs) (females more sensitive) in a 3-month (subchronic) rat study (Huntingdon Life Sciences 2001), adjusted to a human equivalent dose point-of-departure (POD_{HED}) of 3.7 mg/kg-day using BW scaling, divided by a total UF of 300 (3 animal to human, 3 database uncertainty, 10 subchronic study, and 3 intrahuman). ToxStrategies further proposed an RfC of 1.9E-02 mg/m^3 based on a NOAEL of 20 mg/m^3 for a four species (rats, guinea pigs, dogs, squirrel monkeys) 90-day (subchronic) study (Andersen et al. 1977) for effects such as chronic lung inflammation, lung hemorrhage, motor disturbances, seizures, convulsion and death (LOAELs of 159-200 mg/m^3). After duration adjustment (20 mg/m^3 x 23 hours/24 hours x 7 day/7 day = 19.2 mg/m^3), a total UF of 1,000 was used (10 animal to human, 3 database uncertainty, 3 subchronic study, and 10 intrahuman).

However, documentation from August 31, 2011 indicates that ToxStrategies made a minor error in entering data for BMD modeling which resulted in a slightly lower $BMDL_{1SD}$ and POD_{HED} in the original documentation than would have been calculated had the error not occurred. More specifically, in the data entry for the high dose group WBC count, a standard deviation of 1.109 was entered instead of 1.019. The correct standard deviation (1.019) results in a slight increase in the $BMDL_{1SD}$ from 15.1 to 16.1 mg/kg-day, and a corresponding increase in the POD_{HED} from 3.7 to 3.9 mg/kg-day using BW scaling. As such, the POD_{HED} of 3.9 mg/kg-day for decreased WBCs is the correct one for TD consideration.

URS proposed an RfD of 2.5E-03 mg/kg-day based on a NOAEL of 0.25 mg/kg-day for reduced serum enzyme levels (AST/ALT, a.k.a. GOT/GPT) and decreased bone marrow cells in a 6-month (chronic) guinea pig study (Zhu et al. 1987), divided by a total UF of 100 (10 animal to human, 1 database uncertainty, 10 intrahuman). ToxStrategies indicated that without measures of variability and normal reference ranges that the biological significance of these findings in guinea pigs is unclear (also, statistical analyses independent of the study authors cannot be performed). However, in the absence of sufficiently convincing information to the contrary, a conservative assumption is often that statistically significant findings are relevant when an endpoint such as

reduced bone marrow cells are reported (e.g., the reduction was 33% from controls to the 2.5 mg/kg-day dose group), especially when consistent with other effects on cell counts (e.g., decreased WBCs). Therefore, TD believes the results as reported (e.g., significant decreases in bone marrow cells) should still be considered.

RfD Derivation

The proposed RfDs are less than a factor of 5 apart. However, TD believes female rats being more sensitive than males is not justification for ToxStrategies reducing the intrahuman UF to 3 primarily because it is unknown how female rat sensitivity for the species tested relates to intrahuman variability (i.e., it is unknown how inter-gender TK/TD differences conferring differences in gender sensitivity to sulfolane in one homogeneous rodent species relate to potential TK/TD differences affecting sensitivity to sulfolane in the heterogeneous human population, especially considering that individuals in the human population may exhibit different sensitivities not only based on gender, but also age, pre-existing health conditions, etc.). Additionally, typically the most sensitive effects in the most sensitive species (and even gender) are used (bone marrow cell reduction in guinea pigs) but may not have been for their proposed RfD as independent statistics could not be run (even if under a conservative assumption of adversity) and ToxStrategies has other endpoint-specific concerns. TD believes a full intrahuman UF of 10 is justified. Additionally, consistent with TCEQ's proposed *Guidelines to Develop Effects Screening Levels, Reference Values, and Unit Risk Factors (RG-442)*, TD believes BW scaling adequately accounts for both TK and TD in animal-to-human extrapolation (i.e., without use of an additional UF of 3 for TD). Thus, the total UF used by TD with the POD_{HED} of 3.9 mg/kg-day is 300 (3 for database uncertainty, 10 for use of a subchronic study, and 10 for intrahuman variability), which would result in an RfD of 1.3E-02 mg/kg-day (3.9 mg/kg-day / total UF of 300 = 1.3E-02 mg/kg-day). The resulting RfD is considered protective by TD for the effect it is based on (i.e., reduced WBCs), and is also significantly below the NOAEL reported for bone marrow effects in the potentially more sensitive guinea pig (0.25 mg/kg-day). This puts the RfDs considered for adoption a factor of 5 apart.

As TD considers both RfDs under consideration as sufficiently similar to be adequately protective and ToxStrategies used a more robust and modern analysis (e.g., BMDLs, multiple PODs), the TD will adopt the POD proposed by ToxStrategies (POD_{HED} of 3.9 mg/kg-day) divided by a total UF of 300 (as discussed above) for a final RfD of 1.3E-02 mg/kg-day.

RfD = 1.3E-02 mg/kg-day

RfC Derivation

Regarding the RfC proposed by ToxStrategies (1.9E-02 mg/m^3), given the steepness of the dose-response curve based on the subchronic study (a factor of only 8-10 separates no effects from convulsions and death potentially), the TD believes a higher subchronic UF to be justified. Chronic studies could identify more subtle effects (a chronic critical effect) at a LOAEL/NOAEL more than three times lower than the subchronic study. The relatively small difference between very severe effect levels and no effect levels reported in the subchronic study is of concern.

Using a subchronic UF of 10 instead of 3 yields a total UF of 3,000 and a resulting RfC of 6.4E-03 mg/m^3 (19.2 mg/m^3 / total UF of 3,000 = 6.4E-03 mg/m^3).

RfC = 6.4E-03 mg/m^3

Joseph “Kip” Haney, MS
Senior Toxicologist

FINAL
1-30-2012

Provisional Peer-Reviewed Toxicity Values for

Sulfolane
(CASRN 126-33-0)

Superfund Health Risk Technical Support Center
National Center for Environmental Assessment
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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Questions regarding the contents of this document may be directed to the U.S. EPA Office of Research and Development's National Center for Environmental Assessment, Superfund Health Risk Technical Support Center (513-569-7300).

TABLE OF CONTENTS

COMMONLY USED ABBREVIATIONS

BMC	benchmark concentration
BMCL	benchmark concentration lower bound 95% confidence interval
BMD	benchmark dose
BMDL	benchmark dose lower bound 95% confidence interval
HEC	human equivalent concentration
HED	human equivalent dose
IUR	inhalation unit risk
LOAEL	lowest-observed-adverse-effect level
$LOAEL_{ADJ}$	LOAEL adjusted to continuous exposure duration
$LOAEL_{HEC}$	LOAEL adjusted for dosimetric differences across species to a human
NOAEL	no-observed-adverse-effect level
$NOAEL_{ADJ}$	NOAEL adjusted to continuous exposure duration
$NOAEL_{HEC}$	NOAEL adjusted for dosimetric differences across species to a human
NOEL	no-observed-effect level
OSF	oral slope factor
p-IUR	provisional inhalation unit risk
POD	point of departure
p-OSF	provisional oral slope factor
p-RfC	provisional reference concentration (inhalation)
p-RfD	provisional reference dose (oral)
RfC	reference concentration (inhalation)
RfD	reference dose (oral)
UF	uncertainty factor
UF_A	animal-to-human uncertainty factor
UF_C	composite uncertainty factor
UF_D	incomplete-to-complete database uncertainty factor
UF_H	interhuman uncertainty factor
UF_L	LOAEL-to-NOAEL uncertainty factor
UF_S	subchronic-to-chronic uncertainty factor
WOE	weight of evidence

PROVISIONAL PEER-REVIEWED TOXICITY VALUES FOR SULFOLANE (CASRN 126-33-0)

BACKGROUND

A Provisional Peer-Reviewed Toxicity Value (PPRTV) is defined as a toxicity value derived for use in the Superfund Program. PPRTVs are derived after a review of the relevant scientific literature using established Agency guidance on human health toxicity value derivations. All PPRTV assessments receive internal review by a standing panel of National Center for Environment Assessment (NCEA) scientists and an independent external peer review by three scientific experts.

The purpose of this document is to provide support for the hazard and dose-response assessment pertaining to chronic and subchronic exposures to substances of concern, to present the major conclusions reached in the hazard identification and derivation of the PPRTVs, and to characterize the overall confidence in these conclusions and toxicity values. It is not intended to be a comprehensive treatise on the chemical or toxicological nature of this substance.

The PPRTV review process provides needed toxicity values in a quick turnaround timeframe while maintaining scientific quality. PPRTV assessments are updated approximately on a 5-year cycle for new data or methodologies that might impact the toxicity values or characterization of potential for adverse human health effects and are revised as appropriate. It is important to utilize the PPRTV database (http://hhpprtv.ornl.gov) to obtain the current information available. When a final Integrated Risk Information System (IRIS) assessment is made publicly available on the Internet (www.epa.gov/iris), the respective PPRTVs are removed from the database.

DISCLAIMERS

The PPRTV document provides toxicity values and information about the adverse effects of the chemical and the evidence on which the value is based, including the strengths and limitations of the data. All users are advised to review the information provided in this document to ensure that the PPRTV used is appropriate for the types of exposures and circumstances at the site in question and the risk management decision that would be supported by this toxicity assessment.

Other U.S. Environmental Protection Agency (EPA) programs or external parties who may choose to use PPRTVs are advised that Superfund resources will not generally be used to respond to challenges, if any, of PPRTVs used in a context outside of the Superfund program.

QUESTIONS REGARDING PPRTVS

Questions regarding the contents and appropriate use of this PPRTV assessment should be directed to the EPA Office of Research and Development's National Center for Environmental Assessment, Superfund Health Risk Technical Support Center (513-569-7300).

INTRODUCTION

Sulfolane (2,3,5-tetrahydrothiophene-1,1-dioxide; tetramethylene sulfone), CAS No. 126-33-0, is used as an industrial solvent as well as a feedstock in polymer and electronics manufacturing. The chemical structure is shown in Figure 1. The chemical is listed as a high-production-volume chemical by the Organisation for Economic Cooperation and Development (OECD, 2004). Sulfolane has a low vapor pressure, suggesting it has low volatility; however, it is highly soluble in water. A table of physicochemical properties is provided below (see Table 1). The chemical formula is $C_4H_8SO_2$.

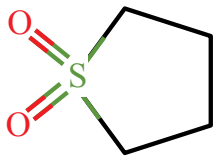

Figure 1. Sulfolane Structure

Table 1. Physicochemical Properties Table for Sulfolane (CASRN 126-33-0)

Property (unit)	Value
Boiling point (ºC)	285[a]
Melting point (ºC)	27.4–27.8[a]
Density (g/cm^3)	1.265[a]
Vapor pressure (mm Hg at 27.6ºC)	0.0062[a]
pH (unitless)	ND
Solubility in water (g/L at 25ºC)	≥100[b]
Relative vapor density (air = 1)	1.266[b]
Molecular weight (g/mol)	120.18[a]

[a]ATSDR (2010a).
[b]OECD (2004).

ND = no data.

No Reference Dose (RfD), Reference Concentration (RfC), or cancer assessment for sulfolane is included in the United States Environmental Protection Agency (U.S. EPA) Integrated Risk Information System (IRIS) (U.S. EPA, 2011a) or on the Drinking Water Standards and Health Advisories List (U.S. EPA, 2009). No RfD or RfC values are reported in the Health Effects Assessment Summary Tables (HEAST) (U.S. EPA, 2011b). The Chemical Assessments and Related Activities (CARA) list does not include a Health and Environmental Effects Profile (HEEP) for sulfolane; there are no noncancer toxicity values (U.S. EPA, 1994). The toxicity of sulfolane has not been reviewed by the Agency for Toxic Substances and Disease

Registry (ATSDR) in a Toxicological Profile (ATSDR, 2010b), but ATSDR did perform a Health Consultation on sulfolane for the Alaska Department of Health and Social Services. ATSDR has recommended an oral exposure limit of 2.5 µg/kg-day based on an oral subchronic study in guinea pigs by Zhu et al. (1987) (ATSDR, 2010a). The toxicity of sulfolane has not been reviewed by the World Health Organization (WHO, 2010). The California Environmental Protection Agency (CalEPA, 2008, 2009) has not derived toxicity values for exposure to sulfolane. No occupational exposure limits for sulfolane have been derived by the American Conference of Governmental Industrial Hygienists (ACGIH, 2010), the National Institute of Occupational Safety and Health (NIOSH, 2011), or the Occupational Safety and Health Administration (OSHA, 2010).

The HEAST (U.S. EPA, 2011b) does not report any values for cancer or a cancer weight-of-evidence (WOE) classification for sulfolane. The International Agency for Research on Cancer (IARC, 2010) has not reviewed the carcinogenic potential of sulfolane. Sulfolane is not included in the *12th Report on Carcinogens* (NTP, 2011). CalEPA (2008) has not prepared a quantitative estimate of carcinogenic potential for sulfolane.

Literature searches were conducted on sources published from 1900 through September 2011 for studies relevant to the derivation of provisional toxicity values for sulfolane, CAS No. 126-33-0. Searches were conducted using EPA's Health and Environmental Research Online (HERO) database of scientific literature. HERO searches the following databases: AGRICOLA; American Chemical Society; BioOne; Cochrane Library; DOE: Energy Information Administration, Information Bridge, and Energy Citations Database; EBSCO: Academic Search Complete; GeoRef Preview; GPO: Government Printing Office; Informaworld; IngentaConnect; J-STAGE: Japan Science & Technology; JSTOR: Mathematics & Statistics and Life Sciences; NSCEP/NEPIS (EPA publications available through the National Service Center for Environmental Publications [NSCEP] and National Environmental Publications Internet Site [NEPIS] database); PubMed: MEDLINE and CANCERLIT databases; SAGE; Science Direct; Scirus; Scitopia; SpringerLink; TOXNET (Toxicology Data Network): ANEUPL, CCRIS, ChemIDplus, CIS, CRISP, DART, EMIC, EPIDEM, ETICBACK, FEDRIP, GENE-TOX, HAPAB, HEEP, HMTC, HSDB, IRIS, ITER, LactMed, Multi-Database Search, NIOSH, NTIS, PESTAB, PPBIB, RISKLINE, TRI, and TSCATS; Virtual Health Library; Web of Science (searches Current Content database among others); World Health Organization; and Worldwide Science. The following databases outside of HERO were searched for toxicity reference values: ACGIH, ATSDR, CalEPA, EPA IRIS, EPA HEAST, EPA HEEP, EPA OW, EPA TSCATS/TSCATS2, NIOSH, NTP, OSHA, and RTECS.

REVIEW OF POTENTIALLY RELEVANT DATA (CANCER AND NONCANCER)

Table 2 provides an overview of the relevant database for sulfolane and includes all potentially relevant repeated-dose short-term-, subchronic-, and chronic-duration studies. The phrase "statistical significance," used throughout the document, indicates a p-value of <0.05, unless otherwise noted.

Table 2. Summary of Potentially Relevant Data for Sulfolane (CASRN 126-33-0)

Category	Number of Male/Female, Strain, Species, Study Type, Study Duration	Dosimetry[a]	Critical effects	NOAEL[a]	BMDL/ BMCL[a]	LOAEL[a]	Reference (Comments)	Notes[b]
Human								
1. Oral[a]								
Subchronic	ND							NA
Chronic	ND							NA
Developmental	ND							NA
Reproductive	ND							NA
Carcinogenicity	ND							NA
2. Inhalation[a]								
Subchronic	ND							NA
Chronic	ND							NA
Developmental	ND							NA
Reproductive	ND							NA
Carcinogenicity	ND							NA

Table 2. Summary of Potentially Relevant Data for Sulfolane (CASRN 126-33-0)

Category	Number of Male/Female, Strain, Species, Study Type, Study Duration	Dosimetry[a]	Critical effects	NOAEL[a]	BMDL/ BMCL[a]	LOAEL[a]	Reference (Comments)	Notes[b]
Animal								
			1. Oral[a]					
Subchronic	**10/10, CD, Rat, drinking water, 13 wk**	**2.1, 8.8, 35.0, 131.7 (males)** **2.9, 10.6, 42.0, 191.1 (females)**	**Statistically significant reductions in total white blood cell (WBC) and differential WBC counts (lymphocyte, basophils, monocyte, and large unstained cell [LUC]) counts in females; increased incidence and severity of cortical tubules with hyaline droplets in the kidneys of males**	**8.8 (males)** **2.9 (females)**	**No models fit to data (reduced WBCs in females)**	**35.0 (males)** **10.6 (females)**	**Huntingdon Life Sciences (2001)**	**PS, PR**
Subchronic	6−12/6−12, Crj:CD(S-D), Rat, gavage, 28 d	0, 60, 200, or 700	Slight reduction of locomotor activity and splenic weight in females; increased relative kidney weight in males; decreased body weight and food consumption in males and females; increased hyaline droplets and eosinophilic bodies in renal tubules of males	60 (male hyaline droplets in kidney) 200 (female decreased spleen weight)	267 (female spleen weight)	200 (male hyaline droplets in kidney) 700 (female decreased spleen weight)	Ministry of Health and Welfare Japan (1996a) as cited by OECD (2004)	PR
Subchronic	80 unspecified sex, and strain, Rat, unspecified oral exposure, 90 d	0, 55.6, 167, or 500	Decreased urine volume, increased urine gamma glutamyl transferase activity, decreased serum alkaline phosphatase, decreased “ICD ;(likely serum isocitrate dehydrogenase),” decreased thrombin.	ND[c]	ND	ND[c]	Zhu et al. (1987a)	PR

Table 2. Summary of Potentially Relevant Data for Sulfolane (CASRN 126-33-0)

Category	Number of Male/Female, Strain, Species, Study Type, Study Duration	Dosimetry[a]	Critical effects	NOAEL[a]	BMDL/ BMCL[a]	LOAEL[a]	Reference (Comments)	Notes[b]
Subchronic	80 unspecified sex and strain, Guinea Pig, unspecified oral exposure, 90 d	0, 55.6, 167, or 500	Decreased ascorbic acid content in adrenal glands; decreased serum alkaline phosphatase levels; decreased WBC count	ND[c]	ND	ND[c]	Zhu et al. (1987b)	PR
Subchronic	20/20, unspecified strain, Guinea Pig, unspecified oral exposure, 3 mo interim sacrifice	0, 0.25, 2.5, 25, or 250	Decreased marrow cell counts; shrinkage of the white pulp in the spleen	ND[c]	ND	ND[c]	Zhu et al. (1987c)	PR
Chronic	20/20, unspecified strain, Guinea Pig, unspecified oral exposure, 6 mo	0, 0.25, 2.5, 25, or 250	Shrinkage of the white pulp in the spleen; fatty degeneration of liver	0.25	ND	2.5	Zhu et al. (1987c)	PR
Developmental	Unreported number of females, Kunming, Mouse, unreported method of oral administration, GDs 6−15	0, 93, 280, 840	Increased fetal resorption; skeletal abnormalities (breastbone malposition, rib fusion)	280 (maternal and developmental)	ND	840 (maternal and developmental)	Zhu et al. (1987d)	PR
Reproductive	12/12, Crj:CD(S-D), Rat, gavage, 41−50 d from 14 days pre-mating to lactation day 3	0, 60, 200, 700	Mortality; decreased number of estrous cases; entire litter loss during lactation; increased number of still births; decreased body-weight gain and food consumption in males and females (premating); decreased birth index and number of viable pups on Days 0 and 4 of lactation	60 (reproductive and developmental)	ND	200 (reproductive and developmental)	Ministry of Health and Welfare Japan (1999) as cited by OECD 2004[d]	PR
Carcinogenicity	ND							NA

Table 2. Summary of Potentially Relevant Data for Sulfolane (CASRN 126-33-0)

Category	Number of Male/Female, Strain, Species, Study Type, Study Duration	Dosimetry[a]	Critical effects	NOAEL[a]	BMDL/ BMCL[a]	LOAEL[a]	Reference (Comments)	Notes[b]
2. Inhalation[a]								
Subchronic	8/7, S-D, Rat, repeated exposure, 8 hr/d, 5 d/wk, 37 d	120	Chronic liver inflammation; chronic lung inflammation	NA	ND	120	Andersen et al. (1977a)	PR
Subchronic	15/0, 15/0, 8/7, S-D, Rat, continuous exposure, 23 hr/d, 90−110 d	2.7, 3.8, 19.2	No effects observed	19.2	ND	NA	Andersen et al. (1977b)	PR
Subchronic	8/7, Hartley, Guinea Pig; repeated exposure, 8 hr/d, 5 d/wk, 37 d	120	Chronic lung inflammation	NA	ND	120	Andersen et al. (1977c)	PR
Subchronic	15/0, 15/0, 8/7, 24/24, 15/15, Hartley, Guinea Pig, continuous exposure, 23 hr/d, 85−110 d	2.7, 3.8, 19.2, 152, and 192	Chronic pleuritis; WBC count significantly lower than preexposure levels; fatty vacuolation of the liver	152	ND	192	Andersen et al. (1977d)	PR
Subchronic	2/0, Beagle, Dog, repeated exposure, 8 hr/d, 5 d/wk, 37 d	120	Chronic lung inflammation	NA	ND	120	Andersen et al. (1977e)	PR

Table 2. Summary of Potentially Relevant Data for Sulfolane (CASRN 126-33-0)

Category	Number of Male/Female, Strain, Species, Study Type, Study Duration	Dosimetry[a]	Critical effects	NOAEL[a]	BMDL/ BMCL[a]	LOAEL[a]	Reference (Comments)	Notes[b]
Subchronic	**1−4 males/group, Beagle, Dog, continuous exposure, 23 hr/d, 90-110 d**	**2.7, 3.8, 19.2, and 192**	**Convulsions, labored breathing, and aggressive behavior in all dogs; severe motor seizures; severe convulsion; chronically inflamed and hemorrhagic lungs**	**19.2**	**ND**	**192 (FEL)**	**Andersen et al. (1977f)**	**PS, PR**
Subchronic	9/0, Squirrel Monkey (*Saimiri sciureus*), repeated exposure, 8 hr/d, 5 d/wk, 37 d	120	Chronic lung inflammation; extreme convulsions; blood-tinged fluid around eyes; pale livers and hearts; fatty metamorphosis of the liver	NA	ND	120 (FEL)	Andersen et al. (1977g)	PR
Subchronic	2−9 males/group, Squirrel Monkey, continuous exposure, 23 h/d, 90−110 d	2.7, 3.8, 19.2, and 192	Mortality and moribundity; chronic pleuritis	19.2	ND	192 (FEL)	Andersen et al. (1977h)	PR
Chronic	ND							NA
Developmental	ND							NA
Reproductive	ND							NA
Carcinogenicity	ND							NA

[a]Dosimetry: The units for oral exposures are expressed as mg/kg-day, while inhalation exposures units are expressed as mg/m^3 NOAEL, BMDL/BMCL, and LOAEL values of long-term exposure (4 weeks and longer) are converted from a discontinuous to a continuous (weekly) exposure. Values from animal developmental studies are not adjusted to a continuous exposure. Values for inhalation were not converted to HEC for respiratory effects due to inadequate information available on particle size of the vapor or for any similar vapor.
[b]Notes: IRIS = utilized by IRIS, date of last update; PS = principal study, PR = peer reviewed, NPR = not peer reviewed.
[c]Incomplete results and lack of description precludes assigning effect levels to the subchronic portion of this study.
[d]Tables and Figures are in English, the text is in Japanese.
NA = not applicable, ND = not determined, FEL = frank effect level.

HUMAN STUDIES

Oral Exposures

No studies were identified on the oral exposure of sulfolane to humans.

Inhalation Exposures

No studies were identified on the inhalation exposure of sulfolane to humans

ANIMAL STUDIES

Oral Exposures

The effects of oral exposure of animals to sulfolane have been evaluated in several subchronic-duration studies (i.e., Huntingdon Life Sciences, 2001; Ministry of Health and Welfare Japan, 1996a, and as summarized in OECD 2004; Zhu et al., 1987), one 6-month chronic-duration study (Zhu et al., 1987), one developmental (Zhu et al., 1987), and one screening-level reproductive study (Ministry of Health and Welfare Japan, 1999, and, as summarized in OECD 2004). No carcinogenicity studies of animals orally exposed to sulfolane have been identified in the literature.

Subchronic Studies

Huntingdon Life Sciences (2001)

The 13-week drinking water study in rats (Huntingdon Life Sciences, 2001) is selected as the principal study for derivation of the subchronic and chronic p-RfDs. In a GLP-compliant, peer-reviewed[1] study by Huntingdon Life Sciences (2001), the study authors administered sulfolane (purity unreported) to CD rats (10/sex/group) in drinking water at concentrations of 0, 25, 100, 400, or 1600 mg/L for 13 weeks. The study authors calculated the actual dosages to be 2.1, 8.8, 35.0, and 131.7 mg/kg-day, respectively, for males and 2.9, 10.6, 42.0, and 191.1 mg/kg-day, respectively, for females. Analytical measurements performed by the study authors indicated that sulfolane was stable in drinking water for 8 days at ambient temperatures and that actual doses were within acceptable limits (96.3−109% of nominal concentrations). Animals were 26−30 days old when supplied by Charles River (UK) Limited, Margate, Kent, England. At the beginning of treatment, animals were 39−43 days old. Males weighed 167−215 g, and females weighed 142−180 g.

Animals were housed in a controlled environment. Temperatures were kept between 19−23°C, and relative humidity was kept between 40−70%. Lighting was supplied in a 12-hour light/dark cycle. The rodent facility was designed and maintained to prevent contamination with external biological and chemical agents. Rats were kept in stainless steel cages with five rats of the same sex in each cage. Food (Rat and Mouse No. 1 Maintenance Diet, Special Services, Ltd., Witham, Essex, England) was provided freely, except on nights before blood sampling. Public tap water was supplied ad libitum in polycarbonate water bottles. Diet and water analyses did not indicate any signs of contamination that may have affected the study.

The study authors examined animals at least twice per day for treatment-related effects and disease. Detailed physical examinations were performed once per week for each animal. Body weight was recorded during acclimatization, at Week 0, once per week throughout treatment, and again at study termination. Food consumption was measured by weighing supplied food and measuring spilled food. Mean weekly consumption and food conversion

[1]Peer-reviewed independently as part of this review.

efficiency were calculated using these data. Water consumption was recorded weekly. All animals were given eye examinations before treatment, focusing on the adnexa, conjunctivae, cornea and sclera, anterior chamber and iris, lens, and vitreous and ocular fundus. Any animals with ocular abnormalities were replaced with healthy animals. During Week 13 of treatment, study authors examined the eyes of animals in the control and high-dose groups.

The study authors performed functional observational battery tests at various times throughout the study. Before treatment and once weekly throughout treatment, animals were examined in the hand for exophthalmos, fur condition, lacrimation, piloerection, reactivity to handling, ease of removal from cage, salivation, and vocalization on handling. Afterward, activity counts, arousal, convulsion, defecation count, gait, grooming, palpebral closure, posture, rearing count, tremor, twitches, and urination were assessed during a 1-minute period in a standard area. Before treatment and during Weeks 6 and 12, animals were examined for approach response, auditory startle reflex, body temperature, body weight, grip strength (forelimbs and hindlimbs), landing foot splay, tail pinch response, pupil reflex, righting reflex, and touch response. Motor activity was measured before treatment and during Weeks 6 and 12 using infrared sensor equipment on animals for 1 hour.

During Week 13, blood samples were collected and examined for hematocrit, hemoglobin, erythrocyte count, total and differential leukocyte count, platelet count, mean cell hemoglobin (MCH), mean cell volume (MCV), and mean cell hemoglobin concentration (MCHC). Romanowsky stains of blood films were examined using light microscopy for abnormal morphology and unusual cell types. Prothrombin time (PT) and activated partial thromboplastin time (APTT) were also measured in additional samples. Blood cell counts also reported large unstained cells (LUCs), which are thought to be larger than normal or atypical lymphocytes. During Week 13, blood plasma was analyzed for alanine aminotransferase (ALT), aspartate aminotransferase (AST), glucose, total cholesterol, creatinine, urea, total protein, albumin, albumin/globulin ratio, and sodium and potassium concentrations.

At sacrifice, the study authors performed a full necropsy including examination of the external body and orifices; neck; and cranial, thoracic, abdominal, and pelvic cavities including their viscera. The study authors recorded organ weights (with bilateral organs weighed together) for the adrenals, brain, epididymides, heart, kidneys, liver, ovaries, spleen, testes, thymus, and uterus with cervix. The following organs were preserved with 10% neutral buffered formalin (except testes and epididymides, which were preserved in Bouin's fluid and then 70% industrial methylated spirits) and examined microscopically: adrenals, aorta, brain, cecum, colon, duodenum, epididymides, femur (with joint), heart, ileum, jejunum, kidneys, liver, lungs (with bronchi), lymph nodes, mammary area, esophagus, ovaries, pancreas, pituitary, prostate, rectum, salivary gland, sciatic nerve, seminal vesicles, skin, spinal cord, spleen, sternum, stomach, testes, thymus, thyroid with parathyroids, trachea, urinary bladder, and uterus with cervix.

In control and high-dose animals, tissue samples were sectioned and stained from the adrenals (cortex and medulla), brain (cerebellum, cerebrum, and midbrain), femur, heart, ileum, kidneys, liver, lungs, mammary area (including overlying skin), spinal cord, stomach, thyroid, uterus, and testes. The study report indicates that kidneys were examined in the 2.1-, 8.8-, and 35.0-mg/kg-day groups (males) and 2.9-, 10.6-, and 42.0-mg/kg-day groups (females). The study authors also examined any abnormal tissues observed in control and all treatment groups.

The study authors did not observe any deaths or treatment-related clinical signs in either males or females. Study authors did not observe treatment-related findings in body weight (see Table B.1), food and water consumption, ocular examinations, functional observational battery tests, organ weight, or macroscopic tissue examination in males or females. Food conversion efficiency was slightly lower than controls during Week 1 in animals receiving the highest dose level (see Table B.2). However, after this time point, food efficiency was roughly comparable with controls in all groups. Females receiving 2.9 mg/kg-day of sulfolane had increased body-weight gain compared with controls but it was not significant. Females exhibited statistically significant decreases in total white blood cells (WBCs), lymphocyte, monocyte, basophil, and LUC counts compared with controls in the 10.6-, 42.0-, and 191.1-mg/kg-day dose groups (see Table B.3). Information was not provided about neutrophils or other cell types, and it is assumed these did not change. Males did not experience similar decreases in these cell counts. There were other intergroup hematological differences reaching statistical significance, with little or no biological relevance, including slightly prolonged prothrombin times in high-dose males and increased mean cell volumes and reduced activated partial thromboplastin times in high-dose females. LUCs were significantly lower in males at 35.0 and 131.7 mg/kg-day compared with control, but the study authors noted there were high values in two of the control animals. Basophils were also significantly different from controls at the two highest doses in both genders.

Males in the high-dose group (i.e., 131.7 mg/kg-day) experienced lowered ALT activities and elevated creatinine concentrations in Week 13 that were statistically significantly different than controls (see Table B.4). Males in the high-dose group had statistically lower AST activities, but authors noted that the mean value in controls was higher due to unusually high levels in two animals. The high-dose animals also displayed reduced plasma sodium concentration compared with controls, but the study authors attributed this decrease to a very low value in one control animal. Histopathological examinations indicated that males dosed with 35.0 and 131.7 mg/kg-day had an increasing incidence and severity of hyaline droplets in the cortical tubules of the kidneys, and increased cortical tubular basophilia; this effect was considered treatment related (see Table B.5). High-dose males also experienced a slightly elevated incidence of granular casts of the renal medulla compared with controls. These effects were not seen in females.

Although there was no assay of functional manifestation of the white cell decreases such as decreased inflammation or compromised immune function, or other effects to the organs of the immune system, the decreases in white cell counts seen in female rats are broad (seen in several cell types), statistically significant, and dose related. Additionally, there was a statistically significant decrease in the spleen weights at the high dose, which supports the immune suppression effect. Also, this effect has been consistently reported in several other studies of sulfolane exposures (albeit at higher exposures) in a different rat strain (Crj:CD[S-D]), species (guinea pigs), and route of exposure (inhalation) (Zhu et al., 1987; Andersen et al., 1977). A LOAEL of 10.6 mg/kg-day and NOAEL of 2.9 mg/kg-day were identified in female rats based on significant decreases in total WBCs, lymphocyte, monocyte, basophil, and LUC counts.

Ministry of Health and Welfare Japan (1996a, cited in OECD, 2004)

In a GLP-compliant, peer-reviewed study, the Ministry of Health and Welfare Japan (1996a, cited in OECD, 2004) administered sulfolane (vehicle and purity unreported) by gavage

to 5-week old male and female Crj:CD(S-D) rats (source unreported) at dose levels of 0, 60, 200, or 700 mg/kg-day for 28 days. The study report was written in Japanese, but it is summarized here based on secondary information from the Organisation for Economic Cooperation and Development (OECD, 2004). Additionally, the data tables in the Ministry of Health and Welfare Japan study report are available in English. There were 6 animals/sex in the 60- and 200-mg/kg-day groups and 12 animals/sex for the groups dosed at 0 and 700 mg/kg-day. After 28 days of treatment, 6 animals in the control and 6 in the 700 mg/kg-day groups were observed for a 14-day recovery period. The exact methods, animal husbandry, and statistical procedures performed by the Ministry of Health and Welfare Japan were not reported by the OECD.

There were no deaths in the control or treatment groups. Males in the 700-mg/kg-day group experienced significantly ($p < 0.01$) lower absolute body weight compared with controls throughout treatment (12−14% body-weight depression from Days 3−28), while high-dose females only differed significantly ($p < 0.01$) from controls for the first 14 days of treatment (11% absolute body-weight depression only on Day 3) (see Table B.6). High-dose males experienced significantly ($p = 0.01$) decreased food consumption for the first 3 weeks of treatment, while females had significantly ($p < 0.01$) decreased food consumption the first week of treatment (see Table B.7). High-dose females experienced decreased locomotor activity (3/12 animals; see Table B.8) during the beginning of the treatment period. Hematology revealed that all dosed male groups had significantly ($p = 0.05$) slightly decreased (2−3%) mean cell hemoglobin concentration (MCHC) after 28 days of treatment, but there was no decrease observed after the 14-day recovery period (see Table B.9). WBC counts in males of the high-dose group were significantly higher ($p = 0.05$) compared with control only after the recovery period and not after the 28-day treatment period. Because only the control and the high-dose groups were examined after recovery, a dose response could not be evaluated. Effects on WBCs in treated females were not observed. High-dose females had significantly reduced mean red blood cell counts (RBCs) and significantly increased mean cell volume (MCV) compared with controls after recovery ($p = 0.01$; see Table B.9). The high-dose males had decreased chloride (<2%) and increased cholinesterase activity (60%) and total bilirubin (29%), but all three parameters returned to normal after the recovery period. The high-dose females had elevated ALT (46% above control) and decreased glucose (15% below control) (see Table B.10). High-dose male rats experienced significantly increased ($p = 0.05$) relative kidney, brain and heart weight (see Table B.11), and increased incidence and severity of hyaline droplets and eosinophilic bodies in the renal tubules at both 200 and 700 mg/kg-day (see Table B.12). Based on observed kidney effects in male rats, a LOAEL of 200 mg/kg-day and a NOAEL of 60 mg/kg-day were identified.

Zhu et al. (1987)

In a single published study that was translated from Chinese for this review, Zhu et al. (1987) conducted a series of studies on the acute, subchronic (90-day), and chronic (6-month) oral toxicity of sulfolane in mice, white rats, and guinea pigs. Study authors also conducted a teratogenicity test and several genotoxicity tests (Ames, bone marrow micronucleus test, and sister chromatid exchange test). The studies are referred to as Zhu et al. (1987a) for the subchronic test on white rats, Zhu et al. (1987b) for the subchronic test on guinea pigs, Zhu et al. (1987c) for the chronic, 6-month toxicity test on guinea pigs, Zhu et al. (1987d) for the developmental toxicity test, and Zhu et al. (1987e) (see Table 4A) for the genotoxicity tests. The Zhu et al. (1987) study is considered a peer-reviewed study because it was reported in a Health Consultation by ATSDR (2010a). The study authors did not state whether the experiment

adhered to GLP guidelines and did not provide data tables in the translation. This report appears to be an extended abstract of the original study with very little useful information for risk assessment purposes. There is, for example, no clear indication of histopathological examination of any tissues in any test described, save for the spleen and liver in the 6-month study. This lack of results precludes assigning any effect levels at least to the 90-day test reports.

Zhu et al. (1987a)

Zhu et al. (1987a) conducted an oral toxicity study on 80 white rats (sex, age, strain not specified) at doses of 0, 55.6, 167, or 500 mg/kg-day sulfolane (purity, vehicle not specified) for 90 days. Study authors did not specify the type (e.g., gavage, drinking water, diet) or frequency of oral administration. It is unclear from the translated study report whether the dosing units were reported as mg/kg food or mg/kg body weight; however, the review by ATSDR (2010a) cites the units as mg/kg body weight per day. After 90 days, the study authors sacrificed animals by femoral artery bleed and measured biochemical parameters, "organ index," and pathology with no mention of histopathology. The study authors did not delineate the specific biochemical parameters examined, nor did they specify the meaning of "organ index." Additionally, the study authors did not provide data tables nor report the type of statistical procedures performed, but they did provide *p*-values to indicate statistical significance.

In rats, no significant changes in biochemical parameters or pathology were reported in the low- and mid-dose groups. However, the study authors reported significant changes in the high-dose group (500 mg/kg-day) including changes in urine volume, increased gamma glutamyl transferase activity in the urine, decreased serum alkaline phosphatase (ALP) activity, decreased ICD (undefined in the study report, but likely serum isocitrate dehydrogenase), and decreased thrombin. The study authors stated that other examined parameters did not exhibit statistically significant changes.

Zhu et al. (1987b)

Zhu et al. (1987b) conducted an oral toxicity study on 80 guinea pigs total (sex, age, group size, strain not clearly indicated) at doses of 0, 55.6, 167, or 500 mg/kg-day sulfolane (purity, vehicle not specified) for 90 days (see description of doses in Zhu et al., 1987a). After 90 days, study authors sacrificed animals by femoral artery bleed and measured specific biochemical parameters, "organ index," and pathology with no mention of histopathology. The study authors did not delineate the specific biochemical parameters examined, nor did they specify the meaning of "organ index." Additionally, the study authors did not report the type of statistical procedures performed, but they did provide *p*-values to indicate statistical significance. In guinea pigs, WBC counts were significantly ($p < 0.05$) decreased relative to controls values in all dose groups, although no other indication of dose response is described or given.

Chronic Study

Zhu et al. (1987c)

Study authors conducted a 6-month, chronic toxicity study where guinea pigs (20/sex/dose) were orally dosed with sulfolane (vehicle and purity not reported) at dose levels of 0, 0.25, 2.5, 25, or 250 mg/kg-day. The translation of the study did not specify the type or frequency of oral exposure (e.g., gavage, diet, drinking water). The study authors conducted biochemical and pathological evaluations on a subset of animals during an interim sacrifice at 3 months and at the end of the study at 6 months. This information is the only experimental design information provided in the translation. The translation did not state the specific

biochemical parameters, organs examined, or whether the "pathology" mentioned was gross pathology or histopathological. The study authors did not provide data tables; however, study authors did provide some values for biochemical parameters and incidence of pathology in the written narrative. The translated study did not mention any methods for statistical analysis. The data from the interim sacrifice at 3 months is considered subchronic-duration data.

At the 3-month interim sacrifice, the study authors reported that ALT, AST, and marrow cell number were lower than controls (see Table B.13). It is not clear from the study report which values were statistically significant. Incidence for shrinkage of white pulp in the spleen in the 0-, 0.25-, 2.5-, 25-, and 250-mg/kg-day groups were reported as 0/14, 0/14, 1/14, 2/14, and 6/14, respectively. The study authors did not present any statistical analysis on data for incidence of white pulp shrinkage in the spleen. Shrinkage in this area may be related to decreased cellularity, which may occur after exposure to agents that cause necrosis of lymphocytes, T-lymphocytes in particular (Elmore, 2006). At 6 months, the study authors reported that the "organ coefficient" of the male guinea pig liver was 40.2 and significantly different from the control group, but the study authors did not specify the meaning of this term. The study authors also reported a dose-response relationship in the increased incidence of fatty degeneration of the liver. This fatty degeneration of the liver is given once in the report, apparently as a total incidence for control and increasing exposures (0/25, 0/22, 2/26, 4/25, and 7/22), and then again as "significant degeneration" at 2.5 mg/kg-day (1/26), 25 mg/kg-day (2/25), and 250 mg/kg-day (5/22). Likewise, shrinkage of splenic white pulp was noted in these "significant" liver exposure groups: 2/26 at 2.5 mg/kg-day, 2/25 at 25 mg/kg-day, and 7/22 at 250 mg/kg-day (see Table B.13). Based on these reported histopathological results, a NOAEL of 0.25 mg/kg-day and a LOAEL of 2.5 mg/kg-day are designated.

Developmental Study

Zhu et al. (1987d)

Zhu et al. (1987d) conducted a developmental toxicity study where female Chinese Kunming mice (number not reported) were orally administered sulfolane (purity not reported) in distilled water vehicle at dose levels of 0, 93, 280, or 840 mg/kg-day on Gestational Days (GDs) 6−15. A positive control (*N*',*N*-methylene-bis-2-amino-5-sulfhydryl-1,3,4-thiadianole) and negative control (distilled water) were also administered to pregnant mice. On GD 18, fetuses were removed, and bodies, organs, and skeletons were examined for abnormalities. The study authors provided no other experimental details or methods of statistical analysis. Study authors reported that the incidence of skeletal abnormalities in the highest dose group (840 mg/kg-day) was significantly higher ($p < 0.01$, statistical test not reported) than the negative control. Study authors also stated that the number of fetal resorptions at the highest dose was greater than that of the negative control (30.16% versus 13.53%, respectively), but statistical significance was not specified. There were no skeletal abnormalities observed in pups in the 280-mg/kg-day group. Data from the study indicate a maternal and developmental NOAEL of 280 mg/kg-day and corresponding LOAEL of 840 mg/kg-day. Although study authors did not indicate whether GLP was followed, the study is considered acceptable because both skeletal and visceral observations of the pups were made, and abnormalities in pups were detected after treatment with sulfolane.

Reproductive Study

Ministry of Health and Welfare Japan (1999)

The Ministry of Health and Welfare Japan (1999) conducted a one-generation reproductive/developmental toxicity screening test that was peer-reviewed by OECD (2004).

The study report is written in Japanese, but it is summarized here based on secondary information from OECD (2004). Additionally, the data tables in the Ministry of Health and Welfare Japan study report are available in English. The study followed OECD 421 guidelines and was conducted under GLP standards. Study authors administered sulfolane (purity unreported) in water by gavage to 10-week-old Crj:CD(S-D) rats (12/sex/group) at doses of 0, 60, 200, or 700 mg/kg-day for 41−50 days. The dosing period extended from 14 days before mating to Lactation Day 3. Males and females were cohoused at a ratio of 1:1 for 14 days until proof of copulation. Clinical observations for general appearance were conducted twice per day for the parental generation and once per day for pups. During the mating period, body weight and food consumption were measured twice per week and then once per week in females during the gestation and lactation period. Estrous cycle was monitored daily until successful copulation. Study authors recorded the following parameters: number of successful copulated pairs, copulation index, paring days until copulation, number of pregnant females, fertility index, number of corpora lutea, number of implantation sites, implantation index, number of living pregnant females, number of pregnant females with parturition, gestation length, number of pregnant females with live pups on Day 0, gestation index, number of pregnant females with live pups on Day 4, delivery index, number of pups alive on Day 0 of lactation, live birth index, sex ratio, number of pups alive on Day 4 of lactation, viability index, and body weight of live pups (on Days 0 and 4). At necropsy, study authors collected organ weights in the parental generation for testes, epididymides, and ovaries. Microscopic examinations of these organs were conducted for animals in the high-dose group only. Pups were examined macroscopically but apparently did not include a detailed organ or skeletal examination.

One high-dose male and one high-dose female died during the treatment period. High-dose animals of both sexes experienced statistically significantly decreased body-weight gain and food consumption during premating; body-weight gain in high-dose males was significantly ($p < 0.01$) decreased throughout the duration of the study (see Tables B.14 and B.15). Study authors also reported soiled fur, diarrhea, and soft stool in males at the 700-mg/kg-day dose group. In females of the 700-mg/kg-day dose group, study authors observed soiled fur during premating and increased relative ovary weight at necropsy (see Table B.16). Females dosed with 700 mg/kg-day had fewer estrous cycles (see Table B.17). The high-dose female group also experienced significantly decreased ($p < 0.01$) birth index, live birth index, and number of pups (on Lactation Days 1 and 4, data shown for LD-4 only; see Table B.18). The number of stillbirths was also significantly increased ($p < 0.01$) in this group. Four dams from this group experienced total litter loss during lactation. Furthermore, the females dosed with 200 mg/kg-day had significantly ($p < 0.05$) decreased delivery and birth indices (see Table B.18). Mean pup weight was significantly decreased on Lactation Day 0 and 4 in the 700-mg/kg-day group ($p < 0.01$) (see Table B.19). Mean litter weights were significantly decreased ($p < 0.05$) compared to control at ≥200 mg/kg-day. At necropsy, study authors did not observe external anomalies in any of the treated pups. A NOAEL of 60 mg/kg-day for reproductive and developmental toxicity based on decreased delivery and birth indexes was identified. The LOAEL was 200 mg/kg-day.

Limitations of the study report include lack of individual body weight, food consumption, uterine weight, and ovarian follicle counts data. Female estrous cycles were counted for 14 days prior to mating, but authors did not report measures of cycle length. Although male rats were examined for reproductive organ atrophy and sperm count, sperm motility and morphology were not measured by study authors.

Carcinogenicity Studies

No human or animal studies pertaining to carcinogenicity of sulfolane via the oral exposure route were identified in the literature.

Inhalation Exposures

The effects of inhalation exposure of animals to sulfolane have been evaluated in one subchronic study testing multiple species (i.e., Andersen et al., 1977). No chronic-duration, developmental, reproductive, or carcinogenicity studies via inhalation exposures have been identified in the literature.

Subchronic Study

Andersen et al. (1977)

In a published, peer-reviewed study, Andersen et al. (1977) conducted a series of tests investigating the subchronic inhalation toxicity of sulfolane to rats, guinea pigs, dogs, and squirrel monkeys. For the subchronic studies, both discontinuous repeated and continual-exposure regimens were implemented by study authors. The methods and results for each exposure group, species, and dosing regimens were not clearly reported. For the sake of clarity, the study is divided into eight separate summaries (Andersen et al., 1977a−h) based on species and exposure regimen (repeated versus continual). The citation and associated experimental design for the subchronic studies are summarized in Table 3. Particle measurements given in the report, "a mean particle size between 1−4 microns in diameter" are sufficient to validate the study by indicating that the material could be breathed into the respiratory tract. This information is, however, not sufficient to perform more formal dosimetry that requires a measurement of mass median aerodynamic diameter (MMAD) and the variability, the sigma g, about that MMAD; therefore, formal dosimetry conversion to HEC for respiratory and extrarespiratory effects is not conducted for this study. Exposure concentrations are duration adjusted from intermittent exposure to continuous exposure 24 hours/day, 7 days/week ($CONC_{adj} = CONC_{study}$ [in mg/m^3] × [Hours per Day Exposed ÷ 24] × [Days Exposed ÷ Total Study Days]).

Table 3. Study Design and Citations for Andersen et al. (1977) Subchronic-Duration Inhalation Studies

Citation	Species and Exposure Regimen
Andersen et al., 1977a	Rat, repeated exposure, 8 hr/d, 5 d/wk
Andersen et al., 1977b	Rat, continual exposure, 23 hr/d, 7 d/wk
Andersen et al., 1977c	Guinea pig, repeated exposure, 8 hr/d, 5 d/wk
Andersen et al., 1977d	Guinea pig, continual exposure, 23 hr/d, 7 d/wk
Andersen et al., 1977e	Dog, repeated exposure, 8 hr/d, 5 d/wk
Andersen et al., 1977f	Dog, continual exposure, 23 hr/d, 7 d/wk
Andersen et al., 1977g	Monkey, repeated exposure, 8 hr/d, 5 d/wk
Andersen et al., 1977h	Monkey, continual exposure, 23 hr/d, 7 d/wk

For the various exposure regimens, study authors concluded that 20 mg/m^3 (19.2 mg/m^3 adjusted for continuous exposure) was the no-effect level for the four species of animals tested (i.e., rats, guinea pigs, dogs, and squirrel monkeys). Thus, the results from all species are mutually supportive. However, for this review, a NOAEL and LOAEL are established for each species and exposure regimen.

Andersen et al. (1977a)

Andersen et al. (1977a) exposed eight male and seven female Sprague-Dawley rats via whole-body inhalation exposure to a concentration of 495 ± 75 mg/m^3 (mean ± standard deviation) aerosolized sulfolane-W (sulfolane plus 3% water to prevent freezing, purity unreported) for 8 hours/day, 5 days/week, for 27 exposure days over a total study duration of 37 days. It is unclear from the study report whether a separate, untreated control group was tested. Study authors indicate changes "compared with controls" in the text; however, the use of an untreated control group was not stated in the experimental design. Adjusted daily concentration was calculated for a total study duration of 37 days (includes weekends) over 24 hours/day, 7 days/week is 120 mg/m^3. Test concentrations within chambers were determined by chromatographic analysis at 6-hour intervals. Rats were housed in Rochester-type chambers with sulfolane reservoirs, and input lines were wrapped in heat tape and maintained above room temperature to prevent freezing. Airflow through the chambers was maintained at 1 m^3/min. Dry chow (unreported brand) and water were provided ad libitum. Authors did not report if the study was conducted according to GLP standards.

Authors determined body weights, total and differential leukocyte counts, hemoglobin concentrations, and hematocrit levels prior to and following exposure. The timepoint of postexposure sampling for the repeat-dose study is not clearly stated in the study report. Additional analyses performed after exposure included creatinine and urea nitrogen levels, cholesterol, lactate dehydrogenase (LDH), AST, ALT, and ALP activity. Rats were observed at unreported intervals for clinical signs of toxicity and abnormal behavior. Authors collected 24-hour urine samples and recorded pH, protein, sugar, ketone bodies, and occult blood. Histopathological analysis was performed on tissues from the lung, bronchus, heart, kidney, bile duct, liver, spleen, stomach, intestine, pancreas, cerebellum, esophagus, thyroid, trachea, lymph node, bladder, and aorta of an unreported number of animals. Authors used Student's *t*-test to compare preexposure and postexposure levels ($p < 0.05$).

Andersen et al. (1977a) observed no mortalities or significant differences in hematology or body weight between preexposure and postexposure levels. A small, nonsignificant decrease in WBC count in sulfolane-treated rats versus control was reported; however, specific values were not reported. Authors observed chronic lung inflammation in all animals but provided no information regarding severity. Study authors reported chronic liver inflammation in 1/5 males and 3/3 females; however, they did not address the inconsistencies between the number of animals reported in each dose group (n = 8 males, 7 females) and the number of animals examined for pathology (n = 5 males, 3 females). Authors concluded that sulfolane vapor is not toxic to rats under these experimental conditions. However, based on chronic lung and liver inflammation observed in rats at the only concentration tested, a LOAEL of 120 mg/m^3 is established.

Andersen et al. (1977b)

Andersen et al. (1977b) administered sulfolane by whole-body inhalation exposure to Sprague-Dawley rats at concentrations of 2.8 ± 1.4 mg/m^3 for 90 days (n = 15 males), 4.0 ± 1.0 mg/m^3 for 110 days (n = 15 males), or 20 ± 6.7 mg/m^3 for 95 days (n = 8 males, 7 females) for 23 hours/day, 7 days/week. Adjusted daily concentrations calculated for continuous exposure over 24 hours/day, 7 days/week are 2.7, 3.8, and 19.2 mg/m^3. No control group was examined for this study. The test substance used, the method of test concentration determination, and animal husbandry are as reported in Andersen et al. (1977a). Authors did not report if this study was conducted in compliance with GLP standards.

Animals were weighed and blood drawn for analysis prior to exposure, after 30 exposure days, after 60 exposure days, and "at the end of exposure." The exact time interval for postexposure examination is unclear. Authors examined all endpoints reported in Andersen et al. (1977a) and used Student's *t*-test to compare preexposure and postexposure data.

Andersen et al. (1977b) reported no mortalities or significant changes in hematology, biochemistry, or body weight between preexposure and postexposure observations. One rat (sex not reported) at the 19.2 mg/m^3 concentration was observed to have a small circumscribed peripheral liver lesion, and 2/7 females at the same exposure had slightly elevated AST, ALT, and LDH activity levels. Authors reported that the liver lesion was not considered to be related to sulfolane exposure, and the dose-related nature of the clinical chemistry observations was unclear. A NOAEL of 19.2 mg/m^3 is established.

Andersen et al. (1977c)

Andersen et al. (1977c) also exposed 8 male and 7 female Hartley-derived guinea pigs to a concentration of 495 ± 75 mg/m^3 sulfolane by whole-body inhalation exposure for 8 hours/day, 5 days/week, for 27 exposure days. The test chemical used is described in Andersen et al. (1977a). Adjusted daily concentration calculated for a total study duration of 37 days (includes weekends) and 24-hour treatment is 120 mg/m^3. It is unclear if an untreated control group was used in this study. Determinations of test concentrations within chambers and husbandry are as described in Andersen et al. (1977a).

Study authors weighed animals and examined hematology prior to exposure. Total and differential leukocyte counts, hemoglobin concentrations, and hematocrit were determined and reevaluated after exposure (exact time interval for postexposure examination is unclear). Endpoints examined are those reported in Andersen et al. (1977a).

Andersen et al. (1977c) reported no significant differences in preexposure and postexposure body weight, hematology, or biochemistry. Preexposure and postexposure WBC, hematocrit, and hemoglobin counts are reported in Table B.20. Although a control group is reported in this table, authors do not mention an untreated group, and it is unclear what this "control" group represents. Authors reported that some degree of chronic lung inflammation (incidence and severity unreported) was observed in all animals. Authors concluded that sulfolane vapor is not toxic to guinea pigs under these experimental conditions. However, based on lung inflammation in guinea pigs, a LOAEL of 120 mg/m^3 is established. The LOAEL represents the only dose tested in this experiment.

Andersen et al. (1977d)

Andersen et al. (1977d) exposed Hartley-derived guinea pigs via whole-body inhalation to sulfolane at concentrations of 2.8 ± 1.4 mg/m^3 for 90 days (n = 15 males), 4.0 ± 1.0 mg/m^3 for 110 days (n = 15 males), 20 ± 6.7 mg/m^3 for 95 days (n = 8 males, 7 females), 159 ± 68 mg/m^3 for 85 days (n = 24 males, 24 females), or 200 ± 48 mg/m^3 for 90 days (n = 15 males, 15 females) exposure for 23 hours/day, 7 days/week. The test chemical used is described in Andersen et al. (1977a). Adjusted daily concentrations calculated for continuous exposure over 24 hours/day, 7 days/week are 2.7, 3.8, 19.2, 152, and 192 mg/m^3, respectively. It is unclear if an untreated control group was used in this study. Some data tables within the study report indicate a control group, but study authors do not explicitly mention this group in the methods section. Determination of test concentrations within chambers and husbandry are as described in Andersen et al. (1977a).

Study authors weighed animals and drew blood for analysis prior to exposure, after 30 exposure days, after 60 exposure days, and "following exposure" (Andersen et al., 1977d). The exact time interval of postexposure examination is unclear. Guinea pigs (exact number unreported) in the 152-mg/m^3 exposure-group were also bled from the toe at 10-day intervals. Authors report that in the 192-mg/m^3 exposure group, eight males and two females were bled after 20 exposure-days and that five males and five females were removed at 30 and 60 exposure-days for examination of body weight, hematology, biochemistry, and necropsy. Tissues from half of these animals were histopathologically examined. Authors examined all endpoints reported previously (Andersen et al., 1977a) and used Student's t-test to compare preexposure and postexposure data.

Authors reported no mortalities, signs of clinical toxicity, or changes in body weight, hematology, biochemistry, or treatment-related pathology at exposures ≤152 mg/m^3. In the 19.2-mg/m^3 exposure group, study authors observed pale livers that they did not consider related to sulfolane treatment, but they did not provide details regarding incidence or severity of the effect.

Authors reported significantly decreased WBC count in the highest exposure group (192 mg/m^3) compared with preexposure levels on Days 20, 30, and 90—but not Day 60 (see Table B.21). However, the data table provided by study authors includes an untreated control group that is not mentioned in their explanation of methods, and it is unclear what this "control" group represents. The WBC count data are not amenable to BMD modeling because the number of animals in each exposure group was not clearly stated. No significant changes in body weight or enzyme activity levels were observed at the 192 mg/m^3 level, although slight, nonsignificant increases in plasma AST and ALT activities were observed at 30 and 60 days. No significant changes in hematocrit or hemoglobin counts were observed at any postexposure sampling period at the 152- or 192-mg/m^3 groups. Chronic pleuritis was observed in all 10 guinea pigs in the 192-mg/m^3 group necropsied at 30 days. Authors reported fatty vacuolization in 4/5 guinea pig livers at 30 days, 6/7 at 60 days, and 4/5 at 90 days; however, the inconsistencies between the number of animals reported to be necropsied previously in the study (0 at 30 days, 5 of each sex at 60 and 90 days) and those reported to be observed (5 at 30 days, 7 at 60 days, and 5 at 90 days) were not addressed. Based on chronic pleuritis, decreased WBC counts, and fatty vacuolation in liver of guinea pigs, a NOAEL of 152 mg/m^3 is established, with a corresponding LOAEL of 192 mg/m^3.

Andersen et al. (1977e)

Andersen et al. (1977e) also exposed two male beagle dogs to a concentration of 495 ± 75 mg/m^3 sulfolane by whole-body inhalation exposure for 8 hours/day, 5 days/week, for 27 exposure days. The test chemical used is described in Andersen et al. (1977a). The adjusted daily concentration calculated for a total study duration of 37 days (includes weekends) and 24 hours/day, 7 days/week is 120 mg/m^3. No untreated control group was used in this study. Determination of test concentrations within chambers and husbandry are as described previously (Andersen et al., 1977a).

Parameters examined in Andersen et al. (1977e) are as described in Andersen et al. (1977a) with the exception that urine samples were not collected. Authors observed no significant changes in body weight, hematology, biochemistry, or pathology. Chronic lung inflammation was observed in both animals (severity not reported). A LOAEL of 120 mg/m^3 is established based on chronic lung inflammation.

Andersen et al. (1977f)

The subchronic inhalation study (Andersen et al., 1977f) is selected as the principal study for derivation of the subchronic RfC and screening chronic RfC. Andersen et al. (1977f) exposed male beagle dogs to concentrations of 2.8 ± 1.4 mg/m^3 sulfolane for 90 days (n = 1), 4.0 ± 1.0 mg/m^3 for 110 days (n = 1), 20 ± 6.7 mg/m^3 for 95 days (n = 2), or 200 ± 48 mg/m^3 for 90 days (n = 4) by whole-body inhalation exposure for 23 hours/day, 7 days/week. Adjusted daily concentrations calculated for continuous treatment over 24 hours/day, 7 days/week are 2.7, 3.8, 19.2, and 192 mg/m^3, respectively. The test chemical used is described in Andersen et al. (1977a). No untreated control group was used in this study. Determination of test concentrations within chambers and husbandry methods are described previously (Andersen et al., 1977a).

Authors examined parameters previously detailed in Andersen et al. (1977a) with the exception that urine samples were not collected. Authors observed no mortalities, signs of clinical toxicity, changes in body weight, hematology, biochemistry, or pathology for the three low-exposure levels (≤19.2 mg/m^3).

At the 192 mg/m^3 exposure-level, authors reported intermittent convulsions (incidence and severity not reported) and frequent displays of fiercely aggressive behavior both toward other dogs and their handlers. During periods of convulsive activity, authors noted episodic, slow, and labored breathing. Authors sacrificed one dog on Exposure Day 11 after the animal experienced many severe generalized motor seizures. Another dog was sacrificed on Exposure Day 29 after becoming so aggressive as to be considered a danger to the handlers. A third dog was removed from the testing chamber after 13 exposure days due to dangerously aggressive behavior. After a 29-day recuperative period, the dog was returned to the testing chamber but died 7 days later (Exposure Day 49) during a violent convulsion. The fourth dog was removed from the chamber on Exposure Day 27 (specific reason not given), allowed to recuperate for 3 days, and survived the full 90 days. Gross pathologic evaluation showed that three of four dogs had pneumonia, and in two of these cases, histologic examination revealed chronically inflamed and hemorrhagic lungs. Authors concluded that these effects were probably due to a combination of pulmonary and nervous system toxicity. Clinical chemistry measurements taken at Day 60 revealed grossly elevated plasma AST, ALT, and LDH levels in one dog (360, 111, and 96 IU/L, respectively; study authors did not report values for an untreated control).

No effects were observed at the 19.2 mg/m^3 exposure level, while animals at the next-highest dose exhibited frank effects such as severe motor seizures, convulsions, and death. Based on information in the study, a FEL of 192 mg/m^3 and a NOAEL of 19.2 mg/m^3 are identified. The NOAEL is used as the POD for derivation of the subchronic and screening chronic p-RfC.

Andersen et al. (1977g)

Andersen et al. (1977g) also exposed nine male squirrel monkeys (*Saimiri sciureus*) to a concentration of 495 ± 75 mg/m^3 sulfolane by whole-body inhalation exposure for 8 hours/day, 5 days/week, for 27 exposure days. The test chemical used is described in Andersen et al. (1977a). Adjusted daily concentration calculated for a total study duration of 37 days (includes weekends) and continuous exposure 24 hours/day, 7 days/week is 120 mg/m^3. No untreated control group was used in this study. Determinations of test concentrations within chambers and husbandry are described previously (Andersen et al., 1977a).

Parameters examined by Andersen et al. (1977g) are as described previously (Andersen et al., 1977a) with the exception that urine samples were not collected. Three animals died, one each on Days 7, 9, and 15. Five others were sacrificed in extremis between Days 9 and 17. Authors noted blood tinged fluid around the eyes (incidence and severity not reported). Pathology revealed pale livers and hearts (incidence and severity not reported), and authors reported 5/6 monkeys had fatty metamorphosis of the liver. Authors also reported a slight, statistically nonsignificant decrease in WBC count and some degree of chronic lung inflammation in all animals (severity not reported). Based on mortality observed at the only concentration tested, an FEL of 120 mg/m^3 is established.

Andersen et al. (1977h)

Andersen et al. (1977h) exposed male squirrel monkeys (*Saimiri sciureus*) to concentrations of 2.8 ± 1.4 mg/m^3 sulfolane for 90 days (n = 9), 4.0 ± 1.0 mg/m^3 for 110 days (n = 9), 20 ± 6.7 mg/m^3 for 95 days (n = 6), or 200 ± 48 mg/m^3 for 90 days (n = 2) by whole-body inhalation exposure for 23 hours/day, 7 days/week. The test chemical used is described in Andersen et al. (1977a). The adjusted daily concentrations calculated for continuous exposure over 24 hours/day, 7 days/week are 2.7, 3.8, 19.2, and 192 mg/m^3, respectively. No untreated control group was used in this study. Determinations of test concentrations within chambers and husbandry are as described in Andersen et al. (1977a).

Authors examined parameters detailed in Andersen et al. (1977a) with the exception that urine samples were not collected. Authors observed no mortalities, signs of clinical toxicity, changes in body weight, hematology, biochemistry, or pathology for the three low-exposure levels (≤19.2 mg/m^3). At the 192 mg/m^3 exposure level, one animal died on Day 3, and the other was sacrificed in a moribund state on Day 4. Authors reported that both animals were heavily infested with parasites and that this could have contributed to their susceptibility. Authors also noted that the monkey sacrificed on Day 4 had chronic pleuritis. No other information was provided. In this exposure regimen, a FEL (death) of 192 mg/m^3 and a NOAEL of 19.2 mg/m^3 are identified.

OTHER DATA (SHORT-TERM TESTS, OTHER EXAMINATIONS)

The database of other experiments on sulfolane includes genotoxicity, effects on thermoregulation, toxicokinetics, and neurotoxicity. The genotoxicity studies are summarized in Table 4A while other studies are summarized in Table 4B.

Table 4A. Summary of Sulfolane Genotoxicity

Endpoint	Test System	Dose/ Concentration[a]	Results[b]		Comments	References
			Without Activation	With Activation		
Genotoxicity studies in prokaryotic organisms						
Reverse mutation	*S. typhimurium* strains TA98, TA100, TA1535, TA1537, TA1538 *E. coli* WP2, WP2uvrA	0−52,000 µg/plate	–	–	No precipitation at any concentration with or without S9	Ministry of Health and Welfare Japan (1996b) as reported in OECD (2004); Shell Oil Company (1982) ; Phillips Petroleum Co. (1994); Zhu et al. (1987e)
SOS repair induction	ND					
Genotoxicity studies in nonmammalian eukaryotic organisms						
Mutation	*S. cerevisiae*	0−5 mg/mL	–	–		Shell Oil Company (1982)
Recombination induction	ND					
Chromosomal aberration	ND					
Chromosomal malsegregation	ND					
Mitotic arrest	ND					
Genotoxicity studies in mammalian cells—in vitro						
Mutation	Mouse lymphoma L5178Y TK cells	0−1000 µg/mL	+	+	Considered positive by study authors but no dose-response observed	Phillips Petroleum Co. (1994); also reported in OECD (2004), however OECD cites study as "Phillips Petroleum Co. (1982)"
Chromosomal aberrations	CHL/IU	0, 0.3, 0.6, or 1.2 mg/mL	–	–	No structural aberrations/polyploidy induced in continuous (24 or 48 hr) or short-term (6 hr) treatment	Ministry of Health and Welfare Japan (1996c) as reported in OECD (2004)
Chromosomal aberrations	Rat liver, RL4 cells	0−1000 µg/mL	–	NA		Shell Oil Company (1982)

Table 4A. Summary of Sulfolane Genotoxicity

Endpoint	Test System	Dose/ Concentration[a]	Results[b]		Comments	References
			Without Activation	With Activation		
Sister chromatid exchange (SCE)	Chinese hamster ovary cells	0−6400 µg/mL	–	–	Growth inhibition at 6400 µg/mL	Phillips Petroleum Co. (1994)
Sister chromatid exchange (SCE)	Human peripheral lymphocytes	0, 0.01, 0.1, 1, 10 mg/mL	–	NR	Growth inhibition at 10 mg/mL	Zhu et al. (1987e)
DNA damage	ND					
DNA adducts	ND					
Genotoxicity studies in mammals—in vivo						
Mouse bone marrow micronucleus test	7-wk-old mouse (strain, sex not specified); orally administered sulfolane	62.5, 125, 250, 500, 1000 mg/kg	–			Zhu et al. (1987e)
Chromosomal aberrations	ND					
Sister chromatid exchange (SCE)	ND					
DNA damage	ND					
DNA adducts	ND					
Mouse biochemical or visible specific locus test	ND					
Dominant lethal	ND					
Genotoxicity studies in subcellular systems						
DNA binding	ND					

[a]Lowest effective dose for positive results, highest dose tested for negative results.
[b]+ = positive, – = negative, NA = not applicable, ND = no data, NR = not reported.

Table 4B. Other Studies

Test	Materials and Methods	Results	Conclusions	References
Carcinogenicity other than oral/inhalation	ND			
Short-term studies	ND			
Metabolism/ toxicokinetics	Male Wistar rat, female rabbit (species unspecified); 100 mg in 2 mL water i.p. injection.	One major metabolite identified (3-hydroxysulfone); metabolite comprised 85% of urinary radioactivity.	Sulfolane is excreted mainly through urine after i.p. injection.	Roberts and Warwick (1961)
Metabolism/ toxicokinetics	Rat, 500 and 1000 mg/kg i.v.	Sulfolane was excreted unchanged in urine; percentage of dose excreted unchanged in the urine was >50% between Days 0 and 2 at 1000 mg/kg; plasma half-life was 3.5−5 hr.	Sulfolane was rapidly distributed in rat after i.v. administration.	Andersen et al. (1976)
Metabolism/ toxicokinetics	12 Sprague-Dawley (S-D) rat, 0.2 mL [^{3}H]-sulfolane (95.3% radiochemical purity, 1.733 mCi/mg specific radioactivity) injected into ligated sections of GI tract. 55 S-D rat, oral dose (40uCi/100g bodyweight), blood and organs weighed and measured for distribution. Pregnant S-D rat (number unspecified) killed 2 hr after administration and examined for distribution to embryo. 3 Male S-D rat, biliary tract plunging tubes collected bile every 10 min within 72 hr after oral dose of [^{3}H]-sulfolane. 5 male S-D rat, oral doses, urine and feces collected every 10 min for 72 hr.	Major absorption site was small intestine, half life for absorption is 0.15 hr; T_{max} (time to maximum plasma concentration) is 1.16 hr; [^{3}H]-sulfolane present in every organ with peak levels at 1 hr, decreasing thereafter; at the peak, levels highest in liver, followed by the kidney and lung; elimination half life of [^{3}H]-sulfolane was longest in brain tissue (31.22 ± 4.68 d); blood concentration in embryos mirrored pregnant dams, while the placenta had a higher concentration; biliary excretion only 3% of administrated dose after 72 hr; excretion in urine and feces accounted for 31 and 15% of administered dose, respectively; kinetic constant for sulfolane is 4.47 hr^{-1}.	Sulfolane is rapidly and completely absorbed and distributed throughout the body; excretion occurs mainly through the urine, with some excretion through the feces.	Zhu et al. (1988)

Table 4B. Other Studies

Test	Materials and Methods	Results	Conclusions	References
Mode of action/ mechanistic	ND			
Immunotoxicity	ND			
Neurotoxicity	Male S-D-derived rat, Hartley derived guinea pig, New Zealand white rabbit, and Swiss albino mouse; doses administered i.v., orally, i.p, and s.c. (exact doses not provided). LD_{50} values calculated from mortality after 1-wk observation.	Hunched posture, increased auditory sensitivity, hyperreactivity, and rapid respiration in rats and mice; at lethal doses, all species experienced clonic-tonic convulsions; LD_{50} values determined for i.v. administration were approximately half the value of those for i.p., oral, and subcutaneous administrations for all species.	Authors concluded that sulfolane has an excitatory effect on the central nervous system following acute administration.	Andersen et al. (1976)
Neurotoxicity	Male S-D rat; single i.p. injection of either saline or 200, 400, or 800 mg/kg-bw; body temperature and metabolic rate were recorded at ambient temperatures of 15°C, 25°C, or 35°C.	No effect of sulfolane at 35°C; at lower ambient temperature, hypothermia and hypometabolism were induced by sulfolane in the rat.	Authors concluded that "hypometabolic and hypothermic efficacy of sulfolane is dependent on ambient temperature."	Gordon et al. (1984)
Neurotoxicity	Male S-D rat; single i.p. injection of either saline or 800 mg/kg; metabolic rate, tail skin temperature, colonic (deep body) temperature, and preferred body temperature were recorded at ambient temperatures of 15°C or 25°C.	Sulfolane reduced metabolic rate and colonic temperature at both ambient temperatures tested; preferred ambient temperature and tail skin temperature unaffected by treatment.	Authors concluded sulfolane toxicity is greater at increased ambient temperatures.	Gordon et al. (1985)

Table 4B. Other Studies

Test	Materials and Methods	Results	Conclusions	References
Neurotoxicity	Male Long-Evans hooded rat; single i.p. injection of either saline or 200, 400, or 800 mg/kg-bw; body temperature and motor activity were measured at ambient temperatures of 20.8°C or 32.3°C.	Hypothermia at doses ≥400 mg/kg-bw at 20.8°C; hypothermia attenuated at 32.3°C; at both temperatures, motor activity decreased at doses ≥400 mg/kg-bw.	Authors concluded that increasing ambient temperature attenuates hypothermia in sulfolane-treated rats, but sulfolane-induced hypoactivity was still evident when tested at both the higher and lower ambient temperatures.	Ruppert and Dyer (1985)
Neurotoxicity	Male Long-Evans hooded rat; single i.p. injection of either saline or 200, 400, or 800 mg/kg-bw sulfolane; visual evoked potentials (VEP) were measured by surgically-implanted electrodes.	No clinical changes in behavior; dose-dependent increase in latency of visual evoked potentials (statistically significant at ≥400 mg/kg-bw); dose-dependent hypothermia.	Authors concluded that acute administration of sulfolane produced clear alterations of visual system function and hypothermia. However, when hypothermia was attenuated by increasing ambient temperature, VEP latencies diminished, indicating that latencies were likely secondary to sulfolane-induced hypothermia.	Dyer et al. (1986)
Neurotoxicity	Male CD-1 mouse; single i.p. injection of saline or 200, 400, 600, or 800 mg/kg sulfolane in volume of 0.3 mL/100 g bw; Experiment 1 measured preferred ambient temperature immediately following injection; Experiment 2 measured metabolic rate and colonic temperature at ambient temperatures of 20°C, 30°C, or 35°C immediately following injection.	Sulfolane-treated mice had significantly lower metabolic rate and body temperature at lower ambient temperatures (<30°C). Mice exhibited behavioral preference for lower ambient temperature after treatment with sulfolane. Percent mortality after a LD_{50} dose of sulfolane increased with increasing ambient temperature.	Authors concluded that sulfolane-treated mice exhibited both autonomic and behavioral decrease in body temperature in order to reduce toxic effects of sulfolane.	Gordon et al. (1986)

Table 4B. Other Studies

Test	Materials and Methods	Results	Conclusions	References
Neurotoxicity	Male Long-Evans hooded rat; single i.p. injection of saline or 200, 400, or 800 mg/kg; Experiment 1 measured presence of audiogenic (AG) seizures and potentiation of pentylenetetrazol (PTZ) seizures; second and third experiments measured effect of body temperature on seizure occurrence using 400- and 800-mg/kg groups (Experiment 2) and the 800-mg/kg group (Experiment 3).	AG seizures occurred in half of the high-dose animals in first two experiments; sulfolane-induced hypothermia showed a protective effect and reduced AG seizure characteristics; doses of 800 mg/kg increased PTZ seizure severity and at 400 and 800 mg/kg, seizure duration was significantly increased; AD seizure activity was not affected significantly by treatment.	Doses of 800 mg/kg sensitized typically resistant rats to AG seizures and increased severity and duration of PTZ seizures; the data suggest that sulfolane treatment does not significantly affect the hippocampus.	Burdette and Dyer (1986)
Neurotoxicity	Male New Zealand White rabbit; single injection of 100, 300, or 1000 µg sulfolane in a 3-µL volume of saline directly into preoptic/anterior hypothalamic (POAH) area via stereotaxically implanted cannula; single injection of 300, 100, or 3000 µg in a 3-µL volume of saline directly into intracerebroventricular (ICV) area; POAH temperature, ear temperature, and metabolic rate were measured.	No statistically significant thermoregulatory effects upon direct injection into POAH; however, significant hyperthermia observed at 60−120 min postdosing upon injection into the ICV at 3000 µg.	Study authors concluded that sulfolane did not directly act on the thermoregulatory neurons of the CNS since no changes in temperature were observed when injected directly into the POAH. This finding contrasts previous findings of systemic (i.p.) injection of sulfolane where hypothermia was induced.	Mohler and Gordon (1989)

ND = not data.

Tests Evaluating Carcinogenicity, Genotoxicity, and/or Mutagenicity

The genotoxicity of sulfolane has been evaluated in bacterial and eukaryotic in vitro systems and has yielded predominantly negative results. In bacterial cells, sulfolane was negative for inducing reverse mutations in *S. typhimurium* strains TA98, TA100, TA1535, TA1537, TA1538, and *E. coli* strains WP2 and WP2uvrA at concentrations up to 52,000 µg/plate, with or without metabolic activation (±S9). Study authors reported that no test compound precipitation or cytotoxicity occurred at concentrations up to 52,000 µg/plate. The only positive result for genotoxicity was reported in an unpublished mouse lymphoma assay by Phillips Petroleum Co. (1994) where study authors exposed L5178Y cells ($T/K^{+/-}$) to sulfolane at concentrations of 0, 60, 90, 135, 202, 301, 449, 670, or 1000 µg/mL; however, OECD (2004) noted that there was no dose response observed, and the survival percentage was not affected by increasing doses. Therefore, OECD considered the positive result as an incorrect interpretation by Phillips Petroleum Co. (1994). Sulfolane was negative for inducing mutations in a nonmammalian eukaryotic test system (*S. cerevisiae*) at concentrations up to 5 mg/mL (±S9) and negative for inducing chromosomal aberrations in CHL/IU and rat liver RL4 cells. Sulfolane did not induce sister chromatid exchange in Chinese hamster ovary cells at concentrations up to 6400 µg/mL, or in human peripheral lymphocytes at 10 mg/ml.

Carcinogenicity Studies

No human or animal studies pertaining to the carcinogenicity of sulfolane via the oral exposure route were identified in the literature.

Other Toxicity Studies (Exposures Other Than Oral or Inhalation)

Information is not available in this regard.

Short-term Studies

Information is not available in this regard.

Metabolism/Toxicokinetic Studies

Zhu et al. (1988), Roberts and Warwick (1961), and Andersen et al. (1976) provide information on the toxicokinetics and metabolism of sulfolane. Data indicate that sulfolane is rapidly and completely absorbed and distributed throughout the body when dosed orally, i.p., or i.v., and excretion occurs mainly through the urine. Further information is provided in Table 4B.

Mode of Action/Mechanistic

Information is not available in this regard.

Immunotoxicity

Information is not available in this regard.

Neurotoxicity

Sulfolane has been shown to elicit changes in thermoregulation of experimental animals Gordon et al. (1984), Ruppert and Dyer (1985), Mohler and Gordon (1989), Dyer et al. (1986), Gordon et al. (1986). Overall, the study authors observed that sulfolane-treated rodents demonstrated increased survivability at lower ambient temperatures. The various studies are presented in Table 4B.

DERIVATION OF PROVISIONAL VALUES

Tables 5 and 6 present a summary of noncancer reference and cancer values, respectively. IRIS data are indicated in the table, if available.

Table 5. Summary of Noncancer Reference Values for Sulfolane (CASRN 126-33-0)

Toxicity Type (units)	Species/Sex	Critical Effect	p-Reference Value	POD Method	POD	UF_C	Principal Study
Subchronic p-RfD (mg/kg-d)	Rat/F	Decreased total and differential WBC counts (lymphocytes, basophils, monocytes, and LUCs)	1×10^{-2}	NOAEL	2.9	300	Huntingdon Life Sciences (2001)
Chronic p-RfD (mg/kg-d)	Rat/F	Decreased total and differential WBC counts (lymphocytes, basophils, monocytes, and LUCs)	1×10^{-3}	NOAEL	2.9	3000	Huntingdon Life Sciences (2001)
Subchronic p-RfC (mg/m^3)	Dog/M	Chronically inflamed and hemorrhagic lungs; neurological effects	2×10^{-2}	NOAEL	19.2	1000	Andersen et al. (1977f)
Screening chronic p-RfC (mg/m^3)	Dog/M	Chronically inflamed and hemorrhagic lungs; neurological effects	2×10^{-3}	NOAEL	19.2	10,000	Andersen et al. (1977f)

Table 6. Summary of Cancer Values for Sulfolane (CASRN 126-33-0)

Toxicity Type	Species/Sex	Tumor Type	Cancer Value	Principal Study
p-OSF	None	None	None	None
p-IUR	None	None	None	None

DERIVATION OF ORAL REFERENCE DOSES

There are five subchronic-duration studies, one chronic-duration study, one developmental study and one reproductive study available involving oral exposures to sulfolane (see Table 2). The most acceptable study to use for deriving an oral reference value is a GLP compliant, peer-reviewed study (Huntingdon Life Sciences, 2001) that identified reduced WBC counts in female rats exposed to sulfolane in drinking water for 13 weeks. Although alternative studies are available (i.e., Ministry of Health and Welfare Japan, 1996a; Zhu et al., 1987), these reports are originally published in a foreign language (Japanese and Chinese, respectively), and the available translations do not contain detailed documentation of experimental methods and study design. The 28-day repeated dose study performed by the Ministry of Health and Welfare Japan (1996a) was reviewed and translated by OECD (2004), but OECD did not provide husbandry data and did not explicitly list the pathology parameters examined. In the translation of the Zhu et al. (1987) paper, information is not provided on the type or frequency of oral exposure, strain of animals used, specific biochemical parameters examined, specific organs examined, type of pathology examined, or methods for statistical analysis. It is unknown whether Zhu et al. (1987) followed GLP guidelines. The methods in the Huntingdon Life Sciences study are well documented, and the study adheres to GLP guidelines. Additionally, the study authors conducted the drinking water study at a lower dose range and examined a wider array of endpoints than the other available studies, and thus, the study was able to detect more sensitive effects of sulfolane. The subchronic-duration study by Huntingdon Life Sciences (2001) is, therefore, selected to derive the subchronic and chronic p-RfDs.

Sulfolane exposure of rats via the drinking water for 13 weeks showed kidneys and WBC as targets of toxicity. The kidney effects in males (hyaline droplets in cortical tubules and increased incidence of cortical tubule basophilia) fit two of the three criteria to be considered related to male rat-specific alpha$_{2u}$globulin nephropathy (as cited in U.S. EPA, 1991). Kidney effects specific to male rats involving alpha$_{2u}$globulin are generally thought to be not applicable to humans since humans do not possess alpha$_{2u}$globulin. However, because the immunohistochemical staining of kidney sections for alpha$_{2u}$globulin was not performed in the Huntingdon Life Sciences (2001) study, the presence of alpha$_{2u}$globulin is not confirmed and the human relevance of this effect cannot be discounted. However, the male rat kidney effects occur at higher doses and are less sensitive than the WBC effects observed in the Huntingdon Life Sciences (2001) study. Therefore, reduced WBC counts in female rats were chosen as the critical effect.

Derivation of Subchronic Provisional RfD (Subchronic p-RfD)

The study by Huntingdon Life Sciences (2001) is selected as the principal study for derivation of the subchronic p-RfD. The critical endpoint is decreased total and differential WBC count (lymphocytes, basophils, monocytes, and LUCs) in female rats. The study was independently peer reviewed by three scientific experts in the summer of 2011, and this peer review supported the study conclusions.[2] The study was performed according to GLP guidelines and otherwise meets the standards of study design and performance, with numbers of animals, examination of potential toxicity endpoints, and presentation of information. Details are provided in the "Review of Potentially Relevant Data" section.

[2]Peer-review report available upon request.

BMD modeling of total WBC count in female rats was attempted using the available continuous models (polynomial, power, Hill, linear) in EPA's BMD software (Version 2.1.2) consistent with EPA's BMD EPA technical guidance (U.S. EPA, 2000). A benchmark response (BMR) of one standard deviation change from the control mean was selected in the absence of a biological rationale for using an alternative BMR. The BMD analysis resulted in significant lack of fit (goodness-of-fit $p < 0.10$) for all continuous models employing nonconstant (modeled) variance (see Table C.1). The homogeneity variance p-value of less than <0.1 indicates that nonconstant variance is the appropriate variance model (and therefore it is inappropriate to assume constant variance for these data).

Because these data were not amenable to BMD modeling, a NOAEL/LOAEL approach was employed to identify the point of departure (POD). The leukocyte data indicate a consistently observed effect, and identify a NOAEL of 2.9 mg/kg-day in females, and thus can be established as a POD for deriving the oral subchronic and chronic RfDs. The LOAEL for this same effect in females is 10.6 mg/kg-day.

No dosimetric adjustments are made because sulfolane was administered continuously via drinking water, and the study authors calculated average daily dose based on body weight and drinking water consumption data in the principal study.

The subchronic p-RfD for sulfolane, based on a NOAEL of 2.9 mg/kg-day in female rats, is derived as follows:

Subchronic p-RfD = NOAEL ÷ UF
= 2.9 mg/kg-day ÷ 300
= **1×10^{-2} mg/kg-day**

Table 7 summarizes the uncertainty factors (UFs) for the subchronic p-RfD of sulfolane.

Table 7. Uncertainty Factors for Subchronic p-RfD of Sulfolane

UF	Value	Justification	Notes
UF_A	10	A UF_A of 10 is applied for interspecies extrapolation to account for potential toxicokinetic and toxicodynamic differences between rats and humans.	
UF_D	3	A UF_D of 3 is applied because there is an acceptable developmental study in mice (Zhu et al., 1987d), but there is only a screening-level one-generation reproduction study in rats (Ministry of Health and Welfare Japan, 1999) via the oral route.	The developmental study in mice was conducted soundly and identified teratogenic effects and is, therefore, considered a valid study.
UF_H	10	A UF_H of 10 is applied for intraspecies differences to account for potentially susceptible individuals in the absence of information on the variability of response to humans.	
UF_L	1	A UF_L of 1 is applied for using a POD based on a NOAEL.	
UF_S	1	A UF_S of 1 is applied because a subchronic study was utilized.	
UF_C ≤3000	300		

Table 8 shows the confidence descriptors for the subchronic RfD.

Table 8. Confidence Descriptors for the Subchronic p-RfD for Sulfolane

Confidence Categories	Designation[a]	Discussion
Confidence in study	H	Confidence in the key study is high. The Huntingdon Life Sciences (2001) study was independently peer reviewed, and was conducted in compliance with GLP.
Confidence in database	M	The database includes subchronic toxicity studies in two species (rat and guinea pig), two chronic toxicity studies (in mice and guinea pigs), one developmental study in mice but no 2-generation reproductive developmental toxicity studies.
Confidence in subchronic p-RfD[b]	M	The overall confidence in the subchronic p-RfD value is medium.

[a]L = low; M = medium; H = high.
[b]The overall confidence cannot be greater than lowest entry in table.

Derivation of a Chronic Provisional RfD (Chronic p-RfD)

The peer-reviewed study by Huntingdon Life Sciences (2001) is selected as the principal study for derivation of the chronic p-RfD. For the same reasons listed above in the subchronic p-RfD discussion, the study by Huntingdon Life Sciences (2001) meets standards of study design and performance. Details are provided in the "Review of Potentially Relevant Data" section.

The chronic p-RfD for sulfolane, based on a NOAEL of 2.9 mg/kg-day in female rats, is derived as follows:

$$\begin{aligned} \textbf{Chronic p-RfD} &= \text{NOAEL} \div \text{UF} \\ &= 2.9 \text{ mg/kg-day} \div 3000 \\ &= \mathbf{1 \times 10^{-3} \text{ mg/kg-day}} \end{aligned}$$

Table 9 summarizes the UFs for the chronic p-RfD of sulfolane. Table 10 shows the confidence descriptors for the chronic p-RfD.

Table 9. Uncertainty Factors for the Chronic p-RfD of Sulfolane

UF	Value	Justification	Notes
UF_A	10	A UF_A of 10 is applied for interspecies extrapolation to account for potential toxicokinetic and toxicodynamic differences between rats and humans.	
UF_D	3	A UF_D of 3 is applied because there is an acceptable developmental study in mice (Zhu et al., 1987d) but only a screening-level one-generation reproduction study in rats (Ministry of Health and Welfare Japan, 1999) via the oral route.	The developmental study in mice was conducted soundly and identified teratogenic effects and is, therefore, considered a valid study.
UF_H	10	A UF_H of 10 is applied for intraspecies differences to account for potentially susceptible individuals in the absence of information on the variability of response to humans.	
UF_L	1	A UF_L of 1 is applied for using a POD based on a NOAEL.	
UF_S	10	A UF_S of 10 is applied because a subchronic study is utilized.	
UF_C ≤3000	3000		

Table 10. Confidence Descriptors for Chronic p-RfD for Sulfolane		
Confidence Categories	**Designation[a]**	**Discussion**
Confidence in study	H	The HLS study is GLP compliant, peer reviewed, and met the standards for an acceptable study
Confidence in database	M	There is an acceptable developmental study but not a two-generational reproductive study
Confidence in subchronic p-RfD[b]	M	The overall confidence descriptor is medium.

[a]L = Low, M = Medium, H = High.
[b]The overall confidence cannot be greater than lowest entry in table.

DERIVATION OF INHALATION REFERENCE CONCENTRATIONS

Derivation of Subchronic Provisional RfC (Subchronic p-RfC)

The study by Andersen et al. (1977f) is selected as the principal study for the derivation of the subchronic p-RfC. The critical endpoint is chronically inflamed and hemorrhagic lungs and neurological effects in male beagle dogs. The study was conducted before GLP guidelines were instituted. Details of the study are provided in the "Review of Potentially Relevant Data" section. The other inhalation studies performed by Andersen et al. (1977a−e,g,h) in several different animal species did not provide more sensitive effects or had improper animal husbandry. A rat study (Andersen et al., 1977b) had the same NOAEL but did not identify a LOAEL. The data are not amenable to benchmark dose modeling. The Andersen et al. (1977f) study provides the lowest POD for developing a subchronic p-RfC, and that POD is protective of all effects seen in all species in all exposure regimens examined in Andersen et al (1977a−h).

The POD in this study is an unadjusted NOAEL of 20 mg/m^3 as reported by the study authors. Dosimetric adjustments were performed for continuous exposure duration. Conversion to HEC is not performed for the respiratory effects due to inadequate information (no MMAD determination) on aerosol particle size. Conversion to HEC is not performed for extrarespiratory (neurologic) effects due to inadequate chemical-specific information about partition coefficients between blood and air.

$$\begin{aligned} NOAEL_{ADJ} &= NOAEL \times (\text{Hours per Day Dosed} \div 24) \times (\text{Days Dosed} \div \text{Total Study Days}) \\ &= 20\ mg/m^3 \times (23 \div 24) \times (95\ \text{Days Dosed} \div 95\ \text{Total Study Days}) \\ &= 20 \times 0.958 \\ &= 19.2\ mg/m^3 \end{aligned}$$

$$\begin{aligned} \textbf{Subchronic p-RfC} &= NOAEL_{ADJ} \div UF \\ &= 19.2\ mg/m^3 \div 1000 \\ &= \mathbf{2 \times 10^{-2}\ mg/m^3} \end{aligned}$$

Table 11 summarizes the UFs for the subchronic p-RfC of sulfolane.

Table 11. Uncertainty Factors for Subchronic p-RfC of Sulfolane			
UF	**Value**	**Justification**	**Notes**
UF_A	10	A UF_A of 10 is applied for interspecies extrapolation to account for potential toxicokinetic and toxicodynamic differences between dogs and humans.	Dosimetric conversion is not performed due to missing aerosol size information.
UF_D	10	A UF_D of 10 is applied because there are no acceptable two-generation reproduction studies or developmental studies via the inhalation route.	
UF_H	10	A UF_H of 10 is applied for intraspecies differences to account for potentially susceptible individuals in the absence of information on the variability of response to humans.	
UF_L	1	A UF_L of 1 is applied because a NOAEL is used.	
UF_S	1	A UF_S of 1 is applied because a subchronic study is utilized.	
UF_C ≤3000	1000		

The confidence of the subchronic p-RfC for sulfolane is low as explained in Table 12 below.

Table 12. Confidence Descriptors for Subchronic p-RfC for Sulfolane		
Confidence Categories	**Designation[a]**	**Discussion**
Confidence in study	L	The study by Andersen et al. (1977a−h) does not provide particle size information for subchronic studies, and the methods are not clearly reported.
Confidence in database	L	The database for subchronic inhalation exposure includes the single study by Andersen et al. (1977a−h).
Confidence in subchronic p-RfD[b]	L	The overall confidence descriptor is low.

[a]L = Low, M = Medium, H = High.
[b]The overall confidence cannot be greater than lowest entry in table.

Derivation of Chronic Provisional RfC (Chronic p-RfC)

No chronic p-RfC can be derived for the following reason: the composite UF for the chronic p-RfC is >3000. Therefore, the value is relegated to a screening-level value, and discussion for the derivation of a screening chronic p-RfC is available in Appendix A.

CANCER WEIGHT-OF-EVIDENCE DESCRIPTOR

Table 13 identifies the cancer weight-of-evidence (WOE) descriptor for sulfolane.

Table 13. Cancer WOE Descriptor for Sulfolane

Possible WOE Descriptor	Designation	Route of Entry (Oral, Inhalation, or Both)	Comments
"Carcinogenic to Humans"	Not selected	NA	
"Likely to Be Carcinogenic to Humans"	Not selected	NA	
"Suggestive Evidence of Carcinogenic Potential"	Not selected	NA	
"Inadequate Information to Assess Carcinogenic Potential"	**Selected**	**Both**	**No carcinogenicity studies on human or animal exposure to sulfolane via the oral or inhalation route are available in the literature.**
"Not Likely to Be Carcinogenic to Humans"	Not selected	NA	

NA = Not Applicable.

MODE-OF-ACTION DISCUSSION

The *Guidelines for Carcinogen Risk Assessment* (U.S. EPA, 2005) define mode of action as "a sequence of key events and processes starting with interaction of an agent with a cell, proceeding through operational and anatomical changes, and resulting in cancer formation" (p. 1−10). Examples of possible modes of carcinogenic action for a given chemical include "mutagenicity, mitogenesis, inhibition of cell death, cytotoxicity with reparative cell proliferation, and immunologic suppression" (p. 1−10). Based on the available literature, sulfolane is not genotoxic. Because there are no available studies on the carcinogenicity of sulfolane, the mode-of-action discussion is precluded.

DERIVATION OF PROVISIONAL CANCER POTENCY VALUES

Derivation of Provisional Oral Slope Factor (p-OSF)

There are insufficient data to assess the carcinogenic potential of sulfolane via the oral route; therefore, derivation of a p-OSF is precluded.

Derivation of Provisional Inhalation Unit Risk (p-IUR)

There are insufficient data to assess the carcinogenic potential of sulfolane via the inhalation route; therefore, derivation of a p-IUR is precluded.

APPENDIX A. PROVISIONAL SCREENING VALUES

For the reasons noted in the main document, it is inappropriate to derive a provisional chronic p-RfC for sulfolane. However, information is available which, although insufficient to support derivation of a provisional toxicity value, under current guidelines, may be of limited use to risk assessors. In such cases, the Superfund Health Risk Technical Support Center summarizes available information in a supplemental and develops a screening value. Appendices receive the same level of internal and external scientific peer review as the main document to ensure their appropriateness within the limitations detailed in the document. Users of screening toxicity values in a supplement to a PPRTV assessment should understand that there is considerably more uncertainty associated with the derivation of a supplement screening toxicity value than for a value presented in the body of the assessment. Questions or concerns about the appropriate use of screening values should be directed to the Superfund Heath Risk Technical Support Center.

DERIVATION OF SCREENING PROVISIONAL INHALATION REFERENCE CONCENTRATION

Derivation of Screening Chronic Provisional RfC (Screening Chronic p-RfC)

Similar to the subchronic p-RfC, the study by Andersen et al. (1977f) is selected as the principal study for the derivation of the screening chronic p-RfC. The critical endpoint is chronically inflamed and hemorrhagic lungs and neurological effects in male beagle dogs. The POD in the Andersen et al. (1977f) study is an unadjusted NOAEL of 20 mg/m^3 as reported by the study authors. Dosimetric adjustments were performed for continuous exposure duration. Conversion to HEC is not performed due to inadequate information on aerosol particle size (no information was given to determine the MMAD).

$$\begin{aligned} NOAEL_{ADJ} &= NOAEL \times (\text{Hours per Day Dosed} \div 24) \times (\text{Days Dosed} \div \text{Total Study Days}) \\ &= 20 \text{ mg/m}^3 \times (23 \div 24) \times (95 \text{ Days Dosed} \div 95 \text{ Total Study Days}) \\ &= 20 \times 0.958 \\ &= 19.2 \text{ mg/m}^3 \end{aligned}$$

$$\begin{aligned} \textbf{Screening Chronic p-RfC} &= NOAEL_{ADJ} \div UF \\ &= 19.2 \text{ mg/m}^3 \div 10{,}000 \\ &= \mathbf{2 \times 10^{-3} \text{ mg/m}^3} \end{aligned}$$

Table A.1 summarizes the UFs for the screening chronic p-RfC of sulfolane. The composite UF of 10,000 relegates this to a screening value. Confidence in the screening value is by definition, low.

Table A.1. Uncertainty Factors for Screening Chronic p-RfC of Sulfolane			
UF	**Value**	**Justification**	**Notes**
UF_A	10	A UF_A of 10 is applied for interspecies extrapolation to account for potential toxicokinetic and toxicodynamic differences between dogs and humans.	Dosimetric conversion is not performed due to missing aerosol size information.
UF_D	10	A UF_D of 10 is applied because there are no acceptable two-generation reproduction studies or developmental studies via the inhalation route, and there is no indication of any other relevant studies that may be relevant for database UF.	
UF_H	10	A UF_H of 10 is applied for intraspecies differences to account for potentially susceptible individuals in the absence of information on the variability of response to humans.	
UF_L	1	A UF_L of 1 is applied because a NOAEL was used.	
UF_S	10	A UF_S of 10 is applied because a subchronic study is utilized and extrapolated for a chronic exposure duration.	
UF_C $\leq$3000	10,000		

APPENDIX B. DATA TABLES

Table B.1. Mean Body Weight and Survival of Male and Female CD Rats After Exposure to Sulfolane for 13 Weeks in Drinking Water[a]

Parameter		Exposure Group, mg/L (Average Daily Dose, mg/kg-d)[b]				
Male		**0**	**25 (2.1)**	**100 (8.8)**	**400 (35.0)**	**1600 (131.7)**
No. of animals		10	10	10	10	10
Body weight[c] (g)	Week 0	192 ± 9.6	196 ± 6.5 (102)	188 ± 9.5 (98)	190 ± 7.8 (99)	193 ± 12.8 (101)
	Week 1	251 ± 10.7	253 ± 8.7 (101)	247 ± 11.9 (98)	250 ± 11.9 (100)	243 ± 16.5 (97)
	Week 2	306 ± 13.2	313 ± 10.3 (102)	305 ± 11.8 (100)	310 ± 18.1 (101)	302 ± 20.8 (99)
	Week 3	348 ± 17.7	357 ± 10.1 (103)	348 ± 15.0 (100)	350 ± 23.3 (101)	347 ± 26.6 (100)
	Week 4	385 ± 18.7	395 ± 13.5 (103)	383 ± 19.2 (99)	388 ± 31.6 (101)	385 ± 29.5 (100)
	Week 5	418 ± 21.7	427 ± 11.1 (102)	412 ± 24.3 (99)	412 ± 32.2 (99)	416 ± 34.0 (100)
	Week 6	437 ± 23.1	453 ± 14.3 (104)	437 ± 29.0 (100)	435 ± 34.3 (100)	441 ± 36.7 (101)
	Week 7	457 ± 25.8	467 ± 14.6 (102)	457 ± 34.5 (100)	455 ± 35.0 (100)	464 ± 38.3 (102)
	Week 8	478 ± 26.1	490 ± 17.3 (103)	478 ± 34.1 (100)	475 ± 37.9 (99)	488 ± 39.2 (102)
	Week 9	498 ± 28.5	514 ± 16.9 (103)	497 ± 38.8 (100)	494 ± 42.2 (99)	509 ± 42.1 (102)
	Week 10	515 ± 30.4	529 ± 20.7 (103)	511 ± 45.9 (99)	511 ± 41.9 (99)	525 ± 43.7 (102)
	Week 11	524 ± 31.5	538 ± 22.8 (103)	522 ± 43.8 (100)	523 ± 45.8 (100)	541 ± 44.7 (103)
	Week 12	541 ± 34.9	558 ± 27.5 (103)	540 ± 49.6 (100)	541 ± 48.6 (100)	558 ± 47.9 (103)
	Week 13	538 ± 32.2	553 ± 26.4 (103)	539 ± 47.9 (100)	536 ± 48.7 (100)	556 ± 51.0 (103)
Body weight gain (g)	Week 0−13	346 ± 37.4	357 ± 26.1 (103)	351 ± 48.2 (101)	346 ± 43.7 (100)	363 ± 43.0 (105)
Survival[d]		10/10 (100)	10/10 (100)	10/10 (100)	10/10 (100)	10/10 (100)

Table B.1. Mean Body Weight and Survival of Male and Female CD Rats After Exposure to Sulfolane for 13 Weeks in Drinking Water[a]

Parameter		Exposure Group, mg/L (Average Daily Dose, mg/kg-d)[b]				
Female		**0**	**25 (2.9)**	**100 (10.6)**	**400 (42.0)**	**1600 (191.1)**
No. of animals		10	10	10	10	10
Body weight (g)	Week 0	163 ± 10.8	160 ± 10.4 (98)	159 ± 7.5 (98)	160 ± 5.3 (98)	158 ± 11.2 (97)
	Week 1	187 ± 14.3	185 ± 14.2 (99)	185 ± 8.7 (99)	187 ± 6.7 (100)	178 ± 13.0 (95)
	Week 2	208 ± 14.4	210 ± 14.5 (101)	208 ± 9.5 (100)	210 ± 8.8 (101)	200 ± 16.5 (96)
	Week 3	226 ± 15.6	227 ± 15.5 (100)	222 ± 12.4 (98)	225 ± 10.1 (100)	216 ± 18.7 (96)
	Week 4	238 ± 16.1	245 ± 15.1 (103)	235 ± 14.6 (99)	237 ± 12.7 (100)	228 ± 18.0 (96)
	Week 5	248 ± 15.4	257 ± 20.1 (104)	248 ± 14.0 (100)	251 ± 12.5 (101)	237 ± 18.0 (96)
	Week 6	254 ± 17.6	266 ± 18.5 (105)	254 ± 15.0 (100)	261 ± 13.4 (103)	246 ± 20.5 (97)
	Week 7	262 ± 19.2	274 ± 18.3 (105)	259 ± 15.8 (99)	268 ± 15.6 (102)	250 ± 22.0 (95)
	Week 8	267 ± 18.5	281 ± 19.3 (105)	262 ± 17.8 (98)	271 ± 16.0 (101)	259 ± 19.4 (97)
	Week 9	272 ± 18.9	290 ± 22.6 (107)	275 ± 16.3 (101)	284 ± 17.5 (104)	265 ± 20.8 (97)
	Week 10	279 ± 16.5	297 ± 24.3 (106)	278 ± 16.1 (100)	291 ± 17.6 (104)	272 ± 22.2 (97)
	Week 11	284 ± 18.0	300 ± 23.3 (106)	280 ± 18.0 (99)	292 ± 20.2 (103)	276 ± 23.3 (97)
	Week 12	287 ± 18.0	304 ± 22.3 (106)	282 ± 19.5 (98)	295 ± 18.1 (103)	279 ± 20.9 (97)
	Week 13	283 ± 19.8	303 ± 26.0 (107)	282 ± 17.1 (100)	292 ± 19.9 (103)	276 ± 22.2 (98)
Body weight gain (g)	Week 0−13	120 ± 12.1	143 ± 19.4[e] (119)	123 ± 12.4 (103)	132 ± 23.3 (110)	118 ± 16.3 (98)
Survival		10/10 (100)	10/10 (100)	10/10 (100)	10/10 (100)	10/10 (100)

[a]Huntingdon Life Sciences (2001).
[b]Average daily doses (mg/kg-day) were calculated by study authors.
[c]Weights expressed as mean ± SD (% of control).
[d]Survival expressed as number surviving/total number (% survival).
[e]Significantly different from control ($p < 0.05$); test was not reported.

Table B.2. Mean Food Conversion Efficiency in Male and Female CD Rats After Exposure to Sulfolane for 13 Weeks in Drinking Water[a]

Parameter		Exposure Group, mg/L (Average Daily Dose, mg/kg-d)[b]				
Male		**0**	**25 (2.1)**	**100 (8.8)**	**400 (35.0)**	**1600 (131.7)**
No. of animals		10	10	10	10	10
Food efficiency[c]	Week 1	28.5	27.3	29.2	29.0	26.2
	Week 2	23.6	26.1	26.2	26.8	27.3
	Week 3	18.9	19.0	19.6	18.2	21.2
	Week 4	18.1	17.8	17.1	17.9	18.2
	Week 5	15.8	14..6	14.1	11.7	15.7
	Week 6	9.3	11.7	11.9	11.1	12.4
	Week 7	9.9	7.0	10.1	9.9	10.7
	Week 8	10.2	10.8	10.3	10.1	11.6
	Week 9	9.8	11.2	9.6	9.3	10.1
	Week 10	8.3	7.1	6.9	8.4	7.6
	Week 11	4.7	4.8	5.8	5.9	8.1
	Week 12	8.0	9.0	8.8	8.8	7.9
	Week 13	ND	ND	ND	ND	ND
Overall	Week 1−13	12.9	12.9	13.4	12.9	13.6
Female		**0**	**25 (2.9)**	**100 (10.6)**	**400 (42.0)**	**1600 (191.1)**
No. of animals		10	10	10	10	10
Food efficiency[c]	Week 1	16.8	17.7	18.9	19.6	14.8
	Week 2	14.8	17.0	16.7	16.3	16.0
	Week 3	12.5	11.6	10.3	10.5	11.1
	Week 4	9.0	12.3	8.7	8.7	8.2
	Week 5	6.9	7.7	8.8	9.6	6.5
	Week 6	3.9	6.6	4.4	6.8	6.6
	Week 7	5.0	5.2	3.2	5.4	3.3
	Week 8	4.0	4.9	2.4	2.1	5.6
	Week 9	4.4	5.9	9.7	8.9	4.7
	Week 10	4.9	5.1	1.9	4.9	4.9
	Week 11	3.9	1.9	1.4	0.7	1.9
	Week 12	2.6	3.4	1.3	2.1	2.2
	Week 13	NE	NE	0.2	NE	NE
Body weight gain (g)	Week 1−13	6.7	7.6	6.8	7.3	6.5

[a]Huntingdon Life Sciences (2001).
[b]Average daily doses (mg/kg-day) were calculated by study authors.
[c]Food conversion efficiency expressed as mean (%) and calculated as overall body-weight gain divided by total food consumed.

ND = not examined; body-weight loss or stasis, NE = not examined

Table B.3. Selected Hematology Data for Rats Exposed to Sulfolane for 13 Weeks in Drinking Water[a]

Parameter	Exposure Group, mg/L (Average Daily Dose, mg/kg-d)[b]				
Male	**0**	**25 (2.1)**	**100 (8.8)**	**400 (35.0)**	**1600 (131.7)**
No. of animals	9	10	10	9	9
MCV (fL)[c]	54.6 ± 0.89	53.8 ± 1.60 (99)	53.3 ± 1.41 (98)	54.4 ± 1.84 (100)	54.7 ± 1.58 (100)
WBC (× 10^9/L)	11.60 ± 2.719	11.61 ± 2.078 (100)	10.90 ± 1.534 (94)	9.47 ± 2.071 (82)	11.34 ± 2.074 (98)
Lymphocyte (× 10^9/L)	9.65 ± 2.430	9.77 ± 1.758 (101)	8.73 ± 1.267 (90)	7.90 ± 1.764 (82)	9.67 ± 1.919 (100)
Basophil (× 10^9/L)	0.02 ± 0.007	0.02 ± 0.009 (100)	0.02 ± 0.005 (100)	0.01 ± 0.007[e] (0.5)	0.01 ± 0.007[d] (0.5)
Monocyte (× 10^9/L)	0.36 ± 0.145	0.36 ± 0.104 (100)	0.38 ± 0.119 (106)	0.27 ± 0.134 (75)	0.25 ± 0.071 (69)
LUC (× 10^9/L)	0.22 ± 0.127	0.14 ± 0.042 (64)	0.16 ± 0.048 (73)	0.12 ± 0.050[e] (55)	0.14 ± 0.039[d] (64)
PT (sec)	13.4 ± 0.80	14.0 ± 1.32 (104)	13.3 ± 0.53 (99)	13.4 ± 1.27 (100)	14.3 ± 0.40[d] (107)
APTT (sec)	17.8 ± 2.24	18.2 ± 3.17 (102)	16.8 ± 2.34 (94)	17.8 ± 2.28 (100)	16.9 ± 2.25 (95)
Female	**0**	**25 (2.9)**	**100 (10.6)**	**400 (42.0)**	**1600 (191.1)**
No. of Animals	10	10	9	9	10
MCV (fL)	55.4 ± 1.39	55.1 ± 1.76 (99)	54.2 ± 1.19 (98)	55.2 ± 1.25 (100)	56.7 ± 1.39[d] (102)
WBC (× 10^9/L)	7.97 ± 2.213	7.63 ± 2.653 (96)	5.41 ± 1.392[e](69)	5.53 ± 1.756[e] (69)	4.54 ± 1.019[e] (57)
Lymphocyte (× 10^9/L)	6.98 ± 2.146	6.36 ± 2.452 (91)	4.39 ± 1.308[e] (63)	4.63 ± 1.564[e] (66)	3.73 ± 0.941[e] (53)
Basophil (× 10^9/L)	0.01 ± 0.006	0.01 ± 0.006 (100)	0.00 ± 0.005[d] (0)	0.00 ± 0.007[d] (0)	0.00 ± 0.004[e] (0)
Monocyte (× 10^9/L)	0.22 ± 0.080	0.23 ± 0.119 (105)	0.13 ± 0.053[d] (59)	0.13 ± 0.040[d] (59)	0.10 ± 0.040[e] (45)
LUC (× 10^9/L)	0.11 ± 0.040	0.11 ± 0.056 (100)	0.06 ± 0.023[d] (55)	0.06 ± 0.026[e] (55)	0.04 ± 0.019[e] (36)
PT (sec)	13.8 ± 0.97	14.1 ± 0.84 (102)	13.8 ± 0.85 (100)	14.1 ± 0.52 (102)	14.0 ± 0.94 (101)
APTT (sec)	17.4 ± 5.21	14.8 ± 1.65 (85)	15.4 ± 2.02 (89)	14.7 ± 1.33 (84)	14.2 ± 2.61[d] (82)

[a]Huntingdon Life Sciences (2001).
[b]Average daily doses (mg/kg-day) were calculated by study authors.
[c]Expressed as group mean ± SD (% of controls).
[d]Significantly different from control ($p \leq 0.05$); Williams' test or Shirley's test.
[e]Significantly different from control ($p \leq 0.01$); Williams' test.

APTT = activated partial thromboplastin time PT = partial thromboplastin time.

Table B.4. Selected Clinical Chemistry Data for Rats Exposed to Sulfolane for 13 Weeks in Drinking Water[a]

Parameter	Exposure Group mg/L (Average Daily Dose, mg/kg-d)[b]				
Male	**0**	**25 (2.1)**	**100 (8.8)**	**400 (35.0)**	**1600 (131.7)**
No. of animals	10	10	10	10	10
ALT (U/L)[c]	49 ± 7.3	43 ± 9.1 (88)	45 ± 11.9 (92)	43 ± 9.5 (88)	38 ± 7.7[d] (78)
AST (U/L)	100 ± 55.1	77 ± 9.5 (77)	83 ± 21.1 (83)	82 ± 30.1 (82)	68 ± 10.0[e] (68)
Creatinine (µmol/L)	49 ± 3.5	48 ± 3.0 (98)	49 ± 2.9 (100)	51 ± 2.1 (104)	53 ± 1.8[e] (108)
Sodium (mmol/L)	141 ± 1.1	140 ± 1.3 (99)	141 ± 0.9 (100)	140 ± 0.9[d] (99)	138 ± 5.1[e] (98)
Total protein (g/L)	68 ± 2.3	69 ± 2.1 (101)	68 ± 2.5 (100)	67 ± 2.4 (99)	67 ± 2.2 (99)
Female	**0**	**25 (2.9)**	**100 (10.6)**	**400 (42.0)**	**1600 (191.1)**
No. of animals	10	10	10	10	10
ALT (U/L)	48 ± 37.5	54 ± 34.3 (113)	43 ± 10.9 (90)	43 ± 14.8 (90)	36 ± 6.1 (75)
AST (U/L)	81 ± 28.9	97 ± 61.2 (120)	85 ± 22.7 (105)	76 ± 18.4 (94)	72 ± 16.2 (89)
Creatinine (µmol/L)	52 ± 3.1	54 ± 5.5 (104)	56 ± 6.9 (108)	55 ± 6.2 (106)	53 ± 4.5 (102)
Sodium (mmol/L)	141 ± 1.0	140 ± 0.6[d] (99)	139 ± 0.9[e] (99)	140 ± 0.8[e] (99)	140 ± 0.8[e] (99)
Total protein (g/L)	75 ± 3.9	75 ± 2.8 (100)	75 ± 5.0 (100)	72 ± 2.6 (196)	73 ± 3.0 (97)

[a]Huntingdon Life Sciences (2001).
[b]Average daily doses (mg/kg-day) were calculated by study authors.
[c]Expressed as group mean ± SD (% of controls).
[d]Significantly different from control ($p \leq 0.05$); Williams' test or Shirley's test.
[e]Significantly different from control ($p \leq 0.01$); Williams' test or Shirley's test.

Table B.5. Selected Histopathological Data in the Kidney for Rats Exposed to Sulfolane for 13 Weeks in Drinking Water[a]

Parameter	Exposure Group mg/L (Average Daily Dose, mg/kg-d)[b]				
Male	**0**	**25 (2.1)**	**100 (8.8)**	**400 (35.0)**	**1600 (131.7)**
Cortical tubular basophilia[c]	3/10 (30)	4/10 (40)	3/10 (30)	3/10 (30)	7/10 (70)
Cortical tubules with hyaline droplets	4/10 (40)	2/10 (20)	4/10 (40)	9/10 (90)	9/10 (90)
Granular casts—medulla	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	2/10 (20)
Cortical scarring	1/10 (1)	0/10 (0)	0/10 (0)	1/10 (10)	1/10 (10)
Medullary cyst(s)	3/10 (30)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)
Interstitial nephritis	1/10 (10)	0/10 (0)	2/10 (20)	0/10 (0)	1/10 (10)
Mineralizations, corticomedullary	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)
Hyaline tubular casts	0/10 (0)	1/10 (10)	0/10 (0)	0/10 (0)	1/10 (10)
Hydronephrosis	0/10 (0)	0/10 (0)	0/10 (0)	1/10 (10)	2/10 (20)
Hyperplasia, papillary epithelium	0/10 (0)	0/10 (0)	0/10 (0)	1/10 (10)	1/10 (10)
Cortical cyst(s)	0/10 (0)	1/10 (10)	1/10 (10)	1/10 (10)	0/10 (0)
Papilla—dilated ducts	0/10 (0)	1/10 (10)	0/10 (0)	0/10 (0)	0/10 (0)
Female	**0**	**25 (2.9)**	**100 (10.6)**	**400 (42.0)**	**1600 (191.1)**
Cortical tubular basophilia	0/10 (0)	1/10 (10)	0/10 (0)	0/10 (0)	1/10 (10)
Cortical tubules with hyaline droplets	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)
Granular casts—medulla	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)
Cortical scarring	0/10 (0)	1/10 (10)	2/10 (20)	1/10 (10)	1/10 (10)
Medullary cyst(s)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)
Interstitial nephritis	0/10 (0)	0/10 (0)	0/10 (0)	1/10 (10)	1/10 (10)
Mineralizations, corticomedullary	1/10 (10)	0/10 (0)	1/10 (10)	0/10 (0)	3/10 (30)
Hyaline tubular casts	0/10 (0)	1/10 (10)	0/10 (0)	0/10 (0)	0/10 (0)
Hydronephrosis	0/10 (0)	0/10 (0)	0/10 (0)	1/10 (10)	0/10 (0)
Hyperplasia, papillary epithelium	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)
Cortical cyst(s)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)
Papilla—dilated ducts	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)

[a]Huntingdon Life Sciences (2001).
[b]Average daily doses (mg/kg-day) were calculated by study authors.
[c]Results presented no. of animals with lesion/no. of animals tested (% incidence).

Table B.6. Mean Body Weight and Survival of Male and Female Sprague-Dawley Rats After Oral Exposure to Sulfolane for 28 Days[a]

Parameter		Exposure Group, mg/kg-d			
		0	**60**	**200**	**700**
Males—treatment period					
No. of animals		12	6	6	12
Body weight[b] (g)	Day 1	151 ± 3	151 ± 3 (100)	151 ± 4 (100)	151 ± 3 (100)
	Day 3	165 ± 4	165 ± 4 (100)	166 ± 6 (101)	146 ± 5[e] (88)
	Day 7	203 ± 7	200 ± 5 (99)	199 ± 5 (98)	177 ± 6[e] (87)
	Day 10	228 ± 10	225 ± 7 (99)	222 ± 5 (97)	198 ± 6[e] (87)
	Day 14	263 ± 13	260 ± 10 (99)	255 ± 6 (97)	226 ± 7[e] (86)
	Day 17	288 ± 17	284 ± 11 (99)	278 ± 8 (97)	247 ± 9[e] (86)
	Day 21	319 ± 21	312 ± 12 (98)	307 ± 8 (96)	276 ± 12[e] (87)
	Day 24	340 ± 23	330 ± 14 (97)	324 ± 10 (95)	292 ± 13[e] (86)
	Day 28	365 ± 27	351 ± 17 (96)	348 ± 7 (95)	317 ± 15[e] (87)
	Gain 1−28	214 ± 25	200 ± 16 (93)	197 ± 7 (92)	166 ± 15[e] (78)
Survival[c]		12/12 (100)	6/6 (100)	6/6 (100)	12/12 (100)
Males—recovery period					
Body weight[b] (g)	Day 28	371 ± 29	NE	NE	341 ± 15[e] (92)
	Day 31	390 ± 31	NE	NE	345 ± 15[e] (88)
	Day 35	413 ± 35	NE	NE	371 ± 17[d] (90)
	Day 28	430 ± 38	NE	NE	386 ± 19[d] (90)
	Day 42	446 ± 44	NE	NE	406 ± 22 (91)
	Gain 28−42	75 ± 15	NE	NE	92 ± 13 (123)
Survival[c]		12/12 (100)	NE	NE	12/12 (100)

Table B.6. Mean Body Weight and Survival of Male and Female Sprague-Dawley Rats After Oral Exposure to Sulfolane for 28 Days[a]

Parameter		Exposure Group, mg/kg-d			
Females—treatment period					
Body weight[b] (g)	Day 1	134 ± 4	134 ± 4 (100)	135 ± 5 (101)	134 ± 4 (100)
	Day 3	142 ± 5	143 ± 7 (101)	140 ± 7 (99)	127 ± 5[e] (89)
	Day 7	159 ± 6	160 ± 6 (101)	157 ± 7 (99)	146 ± 6[e] (92)
	Day 10	167 ± 8	169 ± 7 (101)	169 ± 9 (101)	157 ± 8[d] (94)
	Day 14	180 ± 11	180 ± 6 (100)	181 ± 11 (101)	169 ± 8[d] (94)
	Day 17	190 ± 12	190 ± 7 (100)	191 ± 13 (101)	178 ± 8 (94)
	Day 21	199 ± 13	200 ± 9 (101)	202 ± 14 (102)	189 ± 9 (95)
	Day 24	206 ± 15	203 ± 9 (99)	208 ± 15 (101)	195 ± 10 (95)
	Day 28	215 ± 16	213 ± 9 (99)	217 ± 18 (101)	205 ± 10 (95)
	Gain 1−28	81 ± 14	79 ± 6 (98)	82 ± 15 (101)	72 ± 10 (89)
Survival[c]		12/12 (100)	6/6 (100)	6/6 (100)	12/12 (100)
Females—recovery period					
Body weight[b] (g)	Day 28	214 ± 23	NE	NE	207 ± 13 (97)
	Day 31	219 ± 25	NE	NE	222 ± 14 (101)
	Day 35	226 ± 26	NE	NE	233 ± 17 (103)
	Day 28	233 ± 32	NE	NE	239 ± 20 (103)
	Day 42	239 ± 34	NE	NE	246 ± 22 (103)
	Gain 28−42	25 ± 12	NE	NE	40 ± 11 (160)
Survival[c]		12/12 (100)	NE	NE	12/12 (100)

[a]Ministry of Health and Welfare Japan (1996a).
[b]Weights expressed as mean ± SD (% of control).
[c]Survival expressed as number surviving/total number (% survival).
[d]Significantly different from control ($p = 0.05$); test was not reported.
[e]Significantly different from control ($p = 0.01$); test was not reported.

NE = not examined.

Table B.7. Mean Food Consumption Data of Male and Female Sprague-Dawley Rats After Oral Exposure to Sulfolane for 28 Days[a]

Parameter		Exposure Group (mg/kg-d)			
		0	60	200	700
Males—treatment period					
No. of cages		12	6	6	12
Food consumption[b] (g)	Week 1	25 ± 1	25 ± 3 (100)	25 ± 2 (100)	18 ± 3[c] (72)
	Week 2	29 ± 3	29 ± 3 (100)	29 ± 2 (100)	24 ± 2[c] (83)
	Week 3	30 ± 2	30 ± 2 (100)	31 ± 1 (103)	27 ± 2[c] (90)
	Week 4	32 ± 4	32 ± 2 (100)	33 ± 2 (103)	30 ± 3 (94)
Males—recovery period					
No. of cages		6	0	0	6
Food consumption (g)	Week 0	33 ± 5	NE	NE	30 ± 3 (91)
	Week 1	34 ± 4	NE	NE	34 ± 2 (100)
	Week 2	35 ± 5	NE	NE	35 ± 2 (100)
Females—treatment period					
No. of cages		12	6	6	12
Food consumption (g)	Week 1	19 ± 1	19 ± 1 (100)	19 ± 2 (100)	12 ± 3[c] (63)
	Week 2	19 ± 2	20 ± 1 (105)	20 ± 2 (105)	19 ± 1 (100)
	Week 3	21 ± 2	21 ± 2 (100)	22 ± 3 (105)	20 ± 1 (95)
	Week 4	21 ± 2	19 ± 2 (90)	21 ±3 (100)	21 ± 2 (100)
Females—recovery period					
No. of cages		6	0	0	6
Food consumption (g)	Week 0	21 ± 2	NE	NE	21 ± 2 (100)
	Week 1	21 ± 2	NE	NE	26 ± 1[c] (124)
	Week 2	22 ± 4	NE	NE	23 ± 3 (105)

[a]Ministry of Health and Welfare Japan (1996a).
[b]Food consumption expressed as mean ± SD (% of control).
[c]Significantly different from control ($p = 0.01$); test was not reported.

NE = not examined.

Table B.8. Incidences of Clinical Signs in Female Sprague-Dawley Rats After Oral Exposure to Sulfolane for 28 Days[a]

Weight	Exposure Group (mg/kg-d)			
	0	**60**	**200**	**700**
Treatment period				
No. of animals	12	6	6	12
Decreased locomotor activity[b]	0	0	0	3
Recovery period				
No. of animals	6	0	0	6
Decreased locomotor activity	0	NE	NE	0

[a]Ministry of Health and Welfare Japan (1996a).
[b]Parameter expressed as number of animals affected.

NE = not examined.

Table B.9. Selected Hematological Parameters of Male and Female Sprague-Dawley Rats After Oral Exposure to Sulfolane for 28 Days[a]

Parameter	Exposure Group (mg/kg-d)			
	0	60	200	700
Males—after treatment				
No. of animals	12	6	6	12
RBCs (10^4/μL)[b]	765 ± 32	763 ± 43 (100)	763 ± 29 (100)	772 ± 22 (101)
MCV (fL)	59 ± 3	60 ± 3 (102)	59 ± 2 (100)	61 ± 2 (103)
MCHC (%)	34.6 ± 0.8	33.8 ± 0.4[c] (98)	33.5 ± 0.2[d] (97)	33.6 ± 0.4[d] (97)
WBCs (10^2/μL)	60 ± 16	58 ± 19 (97)	58 ± 13 (97)	64 ± 7 (107)
Males—after recovery period				
No. of animals	6	0	0	6
RBCs (10^4/μL)	784 ± 58	NE	NE	800 ± 49 (102)
MCV (fL)	58 ± 2	NE	NE	58 ± 2 (100)
MCHC (%)	34.3 ± 0.5	NE	NE	34.5 ± 0.8 (101)
WBCs (10^2/μL)	76 ± 19	NE	NE	104 ± 22[c] (137)
Females—after treatment				
No. of animals	12	6	6	12
RBCs (10^4/μL)	773 ± 21	778 ± 32 (101)	752 ± 23 (97)	778 ± 42 (101)
MCV (fL)	57 ± 2	57 ± 2 (100)	57 ± 1 (100)	58 ± 1 (102)
MCHC (%)	34.4 ± 0.4	34.9 ± 0.4 (101)	34.4 ± 0.7 (100)	33.9 ± 0.6 (99)
WBCs (10^2/μL)	49 ± 12	41 ± 12 (84)	38 ± 12 (78)	36 ± 15 (73)
Females—after recovery period				
No. of animals	6	0	0	6
RBCs (10^4/μL)	817 ± 16	NE	NE	781 ± 21[d] (96)
MCV (fL)	55 ± 1	NE	NE	57 ± 1[d] (104)
MCHC (%)	34.6 ± 0.7	NE	NE	34.5 ± 0.3 (100)
WBCs (10^2/μL)	49 ± 14	NE	NE	69 ± 22 (141)

[a]Ministry of Health and Welfare Japan (1996a) .
[b]Parameters expressed as mean ± SD (% of control).
[c]Significantly different from control (p = 0.05); test was not reported.
[d]Significantly different from control (p = 0.01); test was not reported.

RBCs = red blood cells; MCV = mean corpuscular volume; MCHC = mean cell hemoglobin concentration; WBCs = white blood cells; NE = not examined.

Table B.10. Selected Clinical Chemistry Parameters of Male and Female Sprague-Dawley Rats After Oral Exposure to Sulfolane for 28 Days[a]

Parameter	Exposure Group (mg/kg-d)			
	0	60	200	700
Males—after treatment				
No. of animals	6	6	6	6
Alanine aminotransferase (ALT; IU/L)[b]	28 ± 5	28 ± 6 (100)	27 ± 3 (96)	33 ± 5[c] (118)
Total protein (g/dL)	6.33 ± 0.22	6.12 ± 0.12 (97)	6.07 ± 0.13[c] (96)	6.35 ± 0.13 (100)
Thromboglobulin (mg/dL)	80 ± 25	71 ± 13 (89)	86 ± 17 (108)	110 ± 32 (138)
Glucose (mg/dL)	134 ± 11	142 ± 24 (106)	138 ± 9 (103)	130 ± 18 (97)
Total bilirubin (mg/dL)	0.35 ± 0.05	0.35 ± 0.05 (100)	0.40 ± 0.05 (114)	0.45 ± 0.03[d] (129)
ChE (IU/L)	25 ± 9	20 ± 6 (80)	26 ± 4 (104)	40 ± 12[c] (160)
Cl (mEq/L)	104 ± 0	104 ± 1 (100)	104 ± 1 (100)	102 ± 1[d] (98)
Creatinine (mg/dL)	0.51 ± 0.07	0.47 ± 0.06 (92)	0.50 ± 0.05 (98)	0.49 ± 0.04 (96)
Males—after recovery period				
No. of animals	6	0	0	6
Alanine aminotransferase (ALT; IU/L)	31 ± 6	NE	NE	36 ± 9 (116)
Total protein (g/dL)	6.29 ± 0.34	NE	NE	6.09 ± 0.14 (97)
Thromboglobulin (mg/dL)	90 ± 32	NE	NE	63 ± 16 (70)
Glucose (mg/dL)	157 ± 12	NE	NE	143 ± 8[c] (91)
Total bilirubin (mg/dL)	0.28 ± 0.02	NE	NE	0.30 ± 0.05 (107)
ChE (IU/L)	51 ± 22	NE	NE	45 ± 23 (88)
Cl (mEq/L)	103 ± 2	NE	NE	103 ± 1 (100)
Creatinine (mg/dL)	0.63 ± 0.03	NE	NE	0.57 ± 0.04[c] (90)
Females—after treatment				
No. of animals	6	6	6	6
Alanine aminotransferase (ALT; IU/L)	24 ± 5	24 ± 4 (100)	23 ± 4 (96)	35 ± 6[d] (146)
Total protein (g/dL)	6.26 ± 0.36	6.49 ± 0.26 (104)	6.41 ± 0.16 (102)	6.36 ± 0.15 (102)
Thromboglobulin (mg/dL)	26 ± 4	38 ± 12 (146)	44 ± 12[d] (169)	32 ± 12 (123)
Glucose (mg/dL)	130 ± 15	117 ± 13 (90)	124 ± 10 (95)	110 ± 4[c] (85)
Total bilirubin (mg/dL)	0.21 ± 0.01	0.22 ± 0.02 (105)	0.22 ± 0.2 (105)	0.24 ± 0.03 (114)
ChE (IU/L)	304 ± 175	296 ± 106 (97)	281 ± 60 (92)	294 ± 41 (97)
Cl (mEq/L)	106 ± 1	106 ± 1 (100)	106 ± 2 (100)	106 ± 1 (100)
Creatinine (mg/dL)	0.54 ± 0.05	0.55 ± 0.04 (102)	0.53 ± 0.02 (98)	0.53 ± 0.04 (98)

Table B.10. Selected Clinical Chemistry Parameters of Male and Female Sprague-Dawley Rats After Oral Exposure to Sulfolane for 28 Days[a]

Parameter	Exposure Group (mg/kg-d)			
	0	60	200	700
Females—after recovery period				
No. of animals	6	0	0	6
Alanine aminotransferase (ALT; IU/L)	27 ± 6	NE	NE	29 ± 6 (107)
Total protein (g/dL)	6.60 ± 0.29	NE	NE	6.62 ± 0.12 (100)
Thromboglobulin (mg/dL)	46 ± 15	NE	NE	61 ± 19 (133)
Glucose (mg/dL)	139 ± 13	NE	NE	125 ± 10 (90)
Total bilirubin (mg/dL)	0.29 ± 0.05	NE	NE	0.28 ± 0.02 (97)
ChE (IU/L)	292 ± 89	NE	NE	263 ± 47 (90)
Cl (mEq/L)	105 ± 2	NE	NE	105 ± 1 (100)
Creatinine (mg/dL)	0.65 ± 0.10	NE	NE	0.61 ± 0.05 (94)

[a]Ministry of Health and Welfare Japan (1996a).
[b]Parameters expressed as mean ± SD (% of control).
[c]Significantly different from control ($p = 0.05$); test was not reported.
[d]Significantly different from control ($p = 0.01$); test was not reported.

ChE = cholinesterase, Cl = chlorine, NE = not examined.

Table B.11. Selected Organ Weights of Male and Female Rats After Oral Exposure to Sulfolane for 28 Days[a]

Parameter		Exposure Group (mg/kg-d)			
		0	60	200	700
Males—after treatment					
No. of animals		6	6	6	6
Weight[b]	Abs. spleen	0.68 ± 0.05	0.62 ± 0.07 (91)	0.62 ± 0.02 (91)	0.58 ± 0.10 (85)
	Rel. spleen	0.21 ± 0.02	0.20 ± 0.02 (95)	0.20 ± 0.01 (95)	0.20 ± 0.03 (95)
	Abs. liver	9.77 ± 0.72	9.70 ± 0.88 (99)	9.76 ± 0.37 (100)	9.23 ± 0.65 (94)
	Rel. liver	3.04 ± 0.22	3.05 ± 0.15 (100)	3.11 ± 0.10 (102)	3.22 ± 0.15 (106)
	Abs. brain	1.99 ± 0.10	2.03 ± 0.07 (102)	2.00 ± 0.08 (101)	1.95 ± 0.04 (98)
	Rel. brain	0.62 ± 0.03	0.64 ± 0.03 (103)	0.64 ± 0.03 (103)	0.68 ± 0.05[c] (110)
	Abs. kidney	2.47 ± 0.22	2.53 ± 0.14 (102)	2.48 ± 0.11 (100)	2.70 ± 0.30 (109)
	Rel. kidney	0.77 ± 0.04	0.80 ± 0.05 (104)	0.79 ± 0.05 (103)	0.94 ± 0.06[d] (122)
	Abs. heart	1.10 ± 0.11	1.11 ± 0.13 (101)	1.09 ± 0.05 (99)	1.10 ± 0.09 (100)
	Rel. heart	0.34 ± 0.03	0.35 ± 0.03 (103)	0.35 ± 0.01 (103)	0.39 ± 0.03[d] (115)
Males—after recovery period					
No. of animals		6	0	0	6
Weight	Abs. spleen	0.77 ± 0.15	NE	NE	0.68 ± 0.09 (88)
	Rel. spleen	0.19 ± 0.03	NE	NE	0.18 ± 0.02 (95)
	Abs. liver	11.98 ± 1.62	NE	NE	10.56 ± 0.49 (88)
	Rel. liver	2.96 ± 0.23	NE	NE	2.86 ± 0.11 (97)
	Abs. brain	2.08 ± 0.09	NE	NE	2.00 ± 0.06 (96)
	Rel. brain	0.52 ± 0.04	NE	NE	0.54 ± 0.04 (104)
	Abs. kidney	2.69 ± 0.21	NE	NE	2.60 ± 0.27 (97)
	Rel. kidney	0.67 ± 0.05	NE	NE	0.71 ± 0.08 (106)
	Abs. heart	1.28 ± 0.12	NE	NE	1.25 ± 0.11 (98)
	Rel. heart	0.32 ± 0.02	NE	NE	0.34 ± 0.03 (106)

Table B.11. Selected Organ Weights of Male and Female Rats After Oral Exposure to Sulfolane for 28 Days[a]

Parameter		Exposure Group (mg/kg-d)			
		0	60	200	700
Females—after treatment					
Sample size		6	6	6	6
Weight	Abs. spleen	0.48 ± 0.06	0.43 ± 0.05 (90)	0.44 ± 0.08 (92)	0.37 ± 0.03[c] (77)
	Rel. spleen	0.24 ± 0.03	0.22 ± 0.03 (92)	0.23 ± 0.05 (96)	0.20 ± 0.01 (83)
	Abs. liver	5.95 ± 0.32	5.81 ± 0.31 (98)	6.29 ± 0.96 (106)	5.64 ± 0.38 (95)
	Rel. liver	3.00 ± 0.18	2.97 ± 0.08 (99)	3.19 ± 0.27 (106)	3.01 ± 0.15 (100)
	Abs. brain	1.82 ± 0.05	1.87 ± 0.04 (103)	1.83 ± 0.03 (101)	1.81 ± 0.05 (99)
	Rel. brain	0.92 ± 0.05	0.96 ± 0.06 (104)	0.94 ± 0.07 (102)	0.97 ± 0.05 (105)
	Abs. kidney	1.61 ± 0.11	1.58 ± 0.12 (98)	1.63 ± 0.12 (101)	1.60 ± 0.13 (99)
	Rel. kidney	0.82 ± 0.07	0.81 ± 0.07 (99)	0.83 ± 0.03 (101)	0.85 ± 0.07 (104)
	Abs. heart	0.77 ± 0.03	0.74 ± 0.04 (96)	0.76 ± 0.07 (99)	0.73 ± 0.06 (95)
	Rel. heart	0.39 ± 0.02	0.38 ± 0.03 (97)	0.39 ± 0.02 (100)	0.39 ± 0.02 (100)
Females—after recovery period					
Sample size		6	0	0	6
Weight	Abs. spleen	0.44 ± 0.06	NE	NE	0.53 ± 0.05[c] (120)
	Rel. spleen	0.20 ± 0.02	NE	NE	0.24 ± 0.02[c] (120)
	Abs. liver	6.00 ± 0.84	NE	NE	6.69 ± 0.60 (112)
	Rel. liver	2.74 ± 0.15	NE	NE	2.98 ± 0.09[d] (109)
	Abs. brain	1.84 ± 0.09	NE	NE	1.85 ± 0.05 (101)
	Rel. brain	0.85 ± 0.08	NE	NE	0.83 ± 0.06 (98)
	Abs. kidney	1.58 ± 0.23	NE	NE	1.58 ± 0.08 (100)
	Rel. kidney	0.72 ± 0.05	NE	NE	0.71 ± 0.04 (99)
	Abs. heart	0.79 ± 0.09	NE	NE	0.84 ± 0.06 (106)
	Rel. heart	0.36 ± 0.02	NE	NE	0.38 ± 0.03 (106)

[a]Ministry of Health and Welfare Japan (1996a).
[b]Absolute weights expressed as mean ± SD (% of control); relative weights expressed as percentage of body weight.
[c]Significantly different from control ($p = 0.05$); test was not reported.
[d]Significantly different from control ($p = 0.01$); test was not reported.

NE = not examined.

Table B.12. Incidence of Selected Histopathological Findings in the Kidneys of Male and Female Sprague-Dawley Rats After Oral Exposure to Sulfolane for 28 Days[a]

Parameter	Grade[b]	Exposure Group (mg/kg-d)			
		0	60	200	700
Males—after treatment					
No. of animals		6	6	6	6
Hyaline droplets in prox. tubule epithelium	+	1	0	5	1
	++	0	0	1	4
	+++	0	0	0	1
Total incidence		1	0	6[d]	6[d]
Eosinophilic bodies in proximal tubule	+	0	0	5[d]	4[c]
Tubular basophilic change	+	2	1	2	5
Focul tubular dilatation with or without hyaline casts	+	1	1	0	0
Distal tubular dilatation	+	0	0	1	1
Males—after recovery period					
No. of animals		6	0	0	6
Hyaline droplets in prox. tubule epithelium	+	1	NE	NE	3
	++	0	NE	NE	0
	+++	0	NE	NE	0
Total incidence		1	NE	NE	3
Eosinophilic bodies in proximal tubule	+	1	NE	NE	0
Tubular basophilic change	+	4	NE	NE	5
Focul tubular dilatation with or without hyaline casts	+	0	NE	NE	0
Distal tubular dilatation	+	0	NE	NE	0
Females—after treatment					
No. of animals		6	6	6	6
Tubular basophilic change	+	2	NE	NE	1
Fibrotic focus	+	0	NE	NE	1

Table B.12. Incidence of Selected Histopathological Findings in the Kidneys of Male and Female Sprague-Dawley Rats After Oral Exposure to Sulfolane for 28 Days[a]

Parameter	Grade[b]	Exposure Group (mg/kg-d)			
		0	60	200	700
Females—after recovery					
No. of animals	+	6	NE	NE	6
Tubular basophilic change	+	NE	NE	NE	NE
Fibrotic focus	+	NE	NE	NE	NE

[a]Ministry of Health and Welfare Japan (1996a).
[b]Severity grades: + = slight, ++ = moderate, +++ = marked.
[c]Significantly different from control ($p = 0.05$); test was not reported.
[d]Significantly different from control ($p = 0.01$); test was not reported.

NE = not examined.

Table B.13. Clinical Chemistry and Pathology Data of Guinea Pigs Orally Exposed to Sulfolane for 3 or 6 Months[a]

Parameter	Exposure Group (mg/kg-d)				
	0	**0.25**	**2.5**	**25**	**250**
At 3 months					
ALT (IU/100mL)[b]	59.4	ND	ND	40.8	45.8
AST (IU/100mL)	106	ND	ND	ND	71
Marrow cell count ($\times 10^4/mm^3$)	16.43	ND	10.99	12.25	10.56
Spleen—dispersion of white pulp[c]	0/14	0/14	1/14	2/14	6/14
At 6 months					
Spleen—dispersion of white pulp[c]	0/25	0/22	2/26	2/25	7/22
Liver fatty degeneration[c]	0/25	0/22	2/26	4/25	7/22
Liver-significant fatty degeneration[d]	0/25	0/22	1/26	2/25	5/22

[a]Zhu et al. (1987c).
[b]Data are assumed to be group mean. No standard deviation or standard error was provided.
[c]Data are provided as incidence (No. of animals with effect/No. of animals in test group).
[d]More severe fatty degeneration than noted in the line above.

ND = no data

Table B.14. Mean Body Weight and Survival of Male and Female Rats After Oral Exposure to Sulfolane for 41−50 Days[a]

Parameter		Exposure Group (mg/kg-d)			
		0	60	200	700
Male					
Sample size		12	12	12	12 (Days 1−4; 11 thereafter)
Weight[b] (g)	Day 1	367.2 ± 6.7	366.6 ± 5.8 (100)	367.1 ± 6.2 (100)	366.8 ± 5.5 (100)
	Day 4	382.0 ± 10.5	379.7 ± 7.0 (99)	372.3 ± 8.9[d] (97)	322.5 ± 9.8[e] (84)
	Day 8	393.5 ± 11.7	391.8 ± 8.4 (100)	386.5 ± 10.1 (98)	322.0 ± 18.6[e] (82)
	Day 11	403.5 ± 14.1	403.0 ± 13.0 (100)	399.6 ± 13.1 (99)	341.6 ± 14.6[e] (85)
	Day 15	419.3 ± 15.7	416.8 ± 16.6 (99)	417.5 ± 14.1 (100)	370.5 ± 14.1[e] (88)
	Day 18	428.3 ± 16.9	427.3 ± 16.4 (100)	420.5 ± 11.5 (98)	373.1 ± 14.6[e] (87)
	Day 22	445.9 ± 15.4	442.4 ± 16.1 (99)	439.0 ± 12.9 (98)	399.7 ± 18.2[e] (90)
	Day 25	452.3 ± 18.2	453.2 ± 17.7 (100)	450.2 ± 13.6 (100)	411.7 ± 21.8[e] (91)
	Day 29	469.9 ± 19.7	473.3 ± 23.7 (101)	467.5 ± 13.6 (99)	426.8 ± 20.6[e] (91)
	Day 32	474.5 ± 21.0	474.5 ± 22.2 (100)	473.2 ±15.1 (100)	432.9 ± 21.1[e] (91)
	Day 36	479.8 ± 23.3	479.0 ± 20.6 (100)	479.6 ± 15.4 (100)	436.4 ± 20.4[e] (91)
	Day 39	486.4 ± 23.7	485.7 ± 24.9 (100)	485.9 ± 14.3 (100)	440.1 ± 20.1[e] (90)
	Day 43	493.1 ± 25.6	492.2 ± 26.7 (100)	494.2 ± 12.1 (100)	442.8 ± 19.7[e] (90)
	Day 46	495.9 ± 24.2	496.5 ± 27.1 (100)	496.7 ±13.9 (100)	448.2 ± 17.8[e] (90)
	Day 49	500.9 ± 25.6	503.3 ± 25.8 (100)	501.7 ± 13.2 (100)	449.4 ± 21.9[e] (90)
Survival[c]		12/12	12/12	12/12	11/12
Female					
Sample size (except where indicated)		12	12	12	12
Weight (g)	Day 1	218.3 ± 6.5	218.3 ± 6.1 (100)	218.8 ± 6.0 (100)	218.6 ± 5.8 (100)
	Day 4	218.4 ± 6.5	216.1 ± 7.9 (99)	213.3 ± 6.8 (98)	195.1 ± 6.6[e] (89)
	Day 8	224.2 ± 9.0	219.8 ± 7.1 (98)	217.9 ± 7.4 (97)	201.3 ± 6.8[e] (90)
	Day 11	229.4 ± 6.5	225.1 ± 8.6 (98)	222.8 ± 7.9 (97)	216.3 ± 9.1[e] (94)
	Day 15	234.3 ± 7.9	231.0 ± 10.9 (99)	230.7 ± 8.7 (98)	226.7 ± 11.2 (97)
	Day 18	250.0 (*n* = 2)	253.5 (*n* = 2) (101)	243.3 ± 11.7 (*n* = 4) (97)	258.0 (*n* =5) (103)
	Day 22	NR	NR	NR	258.0 (*n* = 2)
	Day 25	NR	NR	NR	272.5 (*n* = 2)
	Day 29	NR	NR	NR	270.0 (*n* = 1)

Table B.14. Mean Body Weight and Survival of Male and Female Rats After Oral Exposure to Sulfolane for 41−50 Days[a]

Parameter		Exposure Group (mg/kg-d)			
Female		**0**	**60**	**200**	**700**
Pregnancy and Lactation Weights					
Sample size		11	12	10	10
Pregnancy	Day 0	240.4 ± 9.9	236.8 ± 11.9 (99)	236.9 ± 8.9 (99)	235.5 ± 23.1 (98)
	Day 7	272.8 ± 8.1	269.2 ± 14.0 (99)	267.8 ± 9.7 (98)	262.8 ± 16.0 (96)
	Day 14	305.9 ± 11.6	300.3 ± 16.1 (98)	295.0 ± 12.2 (96)	291.9 ± 15.1 (95)
	Day 21	388.8 ± 18.0	383.1 ± 22.1 (99)	375.5 ± 14.4 (97)	369.1 ± 29.8 (95)
Lactation	Day 0	274.1 ± 14.3	269.9 ± 17.7 (98)	265.0 ± 9.2 (97)	269.4 ± 8.9 (98)
	Day 4	292.9 ± 17.2	290.3 ± 19.2 (99)	284.3 ± 16.5 (97)	272.2 ± 12.7 (n = 5) (93)
Survival		12/12	12/12	12/12	11/12

[a]Ministry of Health and Welfare Japan (1999).
[b]Weights expressed as mean ± SD (% of control).
[c]Survival expressed as number surviving/total number (% survival); % is calculated.
[d]Significantly different from control ($p < 0.05$); test was not reported.
[e]Significantly different from control ($p < 0.01$); test was not reported.

NR = not reported.

Table B.15. Food Consumption of Male and Female Rats During Oral Exposure to Sulfolane for 41−50 Days[a]

Parameter		Exposure Group (mg/kg-d)			
		0	**60**	**200**	**700**
Male					
No. of animals		12	12	12	12 (Days 1−4; 11 thereafter)
Consumption[b] (g/day)	Day 3	26.9 ± 1.9	27.1 ± 1.3 (101)	24.0 ± 2.3[d] (89)	13.1 ± 2.8[d] (49)
	Day 6	27.6 ± 1.8	28.9 ± 1.7 (105)	26.9 ± 1.4 (97)	12.4 ± 4.9[d] (45)
	Day 10	27.6 ± 2.2	28.9 ± 2.3 (105)	28.1 ± 2.0 (102)	28.1 ± 2.2 (102)
	Day 13	27.7 ± 1.6	28.1 ± 1.4 (101)	28.0 ± 2.0 (101)	27.2 ± 1.9 (98)
	Day 31	25.2 ± 1.6	25.7 ± 1.8 (102)	26.1 ± 1.4 (104)	26.3 ± 2.5 (104)
	Day 34	25.5 ± 1.5	26.7 ± 2.7 (105)	26.8 ± 1.8 (105)	26.4 ± 2.2 (104)
	Day 38	25.3 ± 1.1	26.2 ± 2.4 (104)	25.5 ± 2.0 (101)	26.0 ± 1.8 (103)
	Day 41	25.5 ± 1.2	26.7 ± 3.5 (105)	25.6 ± 2.0 (100)	24.9 ± 2.1 (98)
	Day 45	25.3 ± 3.2	27.6 ± 3.1 (109)	25.3 ± 2.2 (100)	24.8 ± 2.4 (98)
	Day 48	24.5 ± 1.6	27.4 ± 3.1[c] (112)	23.6 ± 2.1 (96)	24.0 ± 3.1 (98)
Female					
No. of animals (except where indicated)		12	12	12	12
Consumption[b] (g/day)	Day 3	16.3 ± 1.7	15.0 ± 2.0 (92)	14.7 ± 1.7 (90)	9.1 ± 1.1[d] (56)
	Day 6	18.0 ± 1.4	17.5 ± 2.2 (97)	17.4 ± 2.0 (97)	10.4 ± 2.4[d] (58)
	Day 10	18.8 ± 1.4	18.7 ± 2.2 (99)	19.0 ± 2.6 (101)	20.7 ± 1.7 (110)
	Day 13	17.9 ± 2.3	17.8 ± 2.3 (99)	18.6 ± 2.1 (104)	19.5 ± 3.3 (109)
Pregnancy and Lactation					
No. of animals		11	12	10	10
Pregnancy	Day 2	21.0 ± 1.7	20.9 ± 3.1 (100)	21.0 ± 2.1 (100)	18.7 ± 2.2 (89)
	Day 9	23.0 ± 1.8	22.9 ± 1.8 (100)	22.9 ± 2.0 (100)	21.2 ± 1.1 (92)
	Day 16	22.5 ± 0.9	22.3 ± 2.3 (99)	21.4 ± 1.7 (95)	22.6 ± 2.2 (100)
	Day 21	20.2 ± 2.6	19.4 ± 2.2 (96)	20.3 ± 1.4 (100)	21.5 ± 2.7 (106)
Lactation	Day 4	30.3 ± 5.1	30.2 ± 4.1 (100)	29.8 ± 4.9 (98)	18.4 ± 9.8[d] (61)

[a]Ministry of Health and Welfare Japan (1999).
[b]Consumption expressed as mean g/day ± SD (% of control).
[c]Significantly different from control ($p < 0.05$); test was not reported.
[d]Significantly different from control ($p < 0.01$); test was not reported.

Table B.16. Ovary Weight of Female Rats After Oral Exposure to Sulfolane for 41−50 Days[a]

Weight	Exposure Group (mg/kg-d)			
	0	60	200	700
Sample size	12	12	12	12
Final Body Weight[b] (g)	289.0 ± 21.3	290.3 ± 19.2 (100)	284.0 ± 15.0 (98)	268.3 ± 14.2[c] (93)
Ovaries (mg)	94.79 ± 11.71	95.51 ± 11.57 (101)	98.39 ± 10.42 (104)	108.63 ± 17.99 (115)
Ovaries (mg %)	32.90 ± 4.36	33.04 ± 4.62 (100)	34.66 ± 3.33 (105)	40.45 ± 5.92[d] (123)

[a]Ministry of Health and Welfare Japan (1999).
[b]Weights expressed as mean ± SD (% of control).
[c]Significantly different from control ($p < 0.05$); test was not reported.
[d]Significantly different from control ($p < 0.01$); test was not reported.

Table B.17. Selected Reproductive Parameters of Female Rats After Oral Exposure to Sulfolane for 41−50 Days[a]

Parameter	Exposure Group (mg/kg-d)			
	0	60	200	700
Number of females	12	12	12	12
Number of estrous cases before mating (14 d)[b]	3.5 ± 0.5	3.3 ± 0.5 (94)	3.2 ± 0.4 (91)	2.2 ± 0.9[e] (63)
Number of pregnant females	11	12	10	10
Fertility index[c]	91.7	100.0	83.3	90.9
Number of pregnant females with live pups	11	12	10	10
Number of males	12	12	12	11
Number of males with successful copulation	12	12	12	10
Copulation index[d]	100.0	100.0	100.0	91.7

[a]Ministry of Health and Welfare Japan (1999).
[b]Presented as mean ± SD (% of control).
[c]Express as %; calculated using the equation: (number of females with successful copulation/number if females) × 100.
[d]Expressed as %; calculated using the equation: (number of males with successful copulation/number of males) × 100.
[e]Significantly different from control ($p < 0.01$); test was not reported.

Table B.18. Selected Pup Observations of Female Rats Exposed to Sulfolane for 41−50 Days[a]

Parameter	Exposure Group (mg/kg-d)			
	0	60	200	700
Number of dams	11	12	10	10
Birth index[b]	96.3 ± 6.5	95.8 ± 4.8 (99)	90.5 ± 5.1[f] (94)	71.6 ± 26.2[g] (74)
Dead pups on Lactation Day 0	0.3 ± 0.5	0.2 ± 0.4 (67)	0.2 ± 0.4 (67)	3.6 ± 4.4[g] (1200)
Delivery index[c]	98.1 ± 4.5	96.9 ± 4.0 (99)	91.8 ± 4.1[f] (94)	94.0 ± 6.7 (96)
Live birth index[d]	98.1 ± 3.3	98.8 ± 2.8 (101)	98.7 ± 2.8 (101)	75.9 ± 26.2[g] (77)
Live pups on Lactation Day 4	14.8 ± 1.8	15.0 ± 1.9 (101)	13.7 ± 1.3 (93)	4.0 ± 5.6[g] (27)
Viability index[e]	99.5 ± 1.8	100.0 ± 0.0 (101)	97.3 ± 3.5 (98)	29.2 ± 40.4[g] (29)

[a]Ministry of Health and Welfare Japan (1999).
[b](Number of live pups born/number of implantation scars) × 100.
[c](Number of pups born/number of implantation scars) × 100 (%).
[d](Number of live pups born/number of pups born) × 100.
[e](Number of live pups on day 4/number of live pups born) × 100.
[f]Significantly different from control ($p < 0.05$); test was not reported.
[g]Significantly different from control ($p < 0.01$); test was not reported.

Table B.19. Body Weights of Pups Born to Female Rats Exposed to Sulfolane for 41−50 Days[a]

Parameter		Exposure Group (mg/kg-day)			
		0	60	200	700
Number of dams (except where indicated otherwise)		11	12	10	10
Mean pup weight[b]	Lactational Day 0	6.41 ± 0.33	6.03 ± 0.35 (94)	6.05 ± 0.35 (94)	5.16 ± 0.51[d] (80)
	Lactational Day 4	9.57 ± 0.81	9.41 ± 0.99 (98)	9.43 ± 1.13 (99)	5.96 ± 1.52[d] (n = 5) (62)
Litter weight	Lactational Day 0	95.27 ± 11.58	89.83 ± 7.64 (94)	85.11 ± 5.60[c] (89)	59.22 ± 27.00[d] (62)
	Lactational Day 4	141.07 ± 16.51	139.77 ± 10.53 (99)	128.00 ± 8.19[c] (91)	48.94 ± 46.11[d] (n = 5) (35)

[a]Ministry of Health and Welfare Japan (1999).
[b]Weights expressed as mean ± SD (% of control).
[c]Significantly different from control ($p < 0.05$); test was not reported.
[d]Significantly different from control ($p < 0.01$); test was not reported.

Table B.20. Hematological Parameters of Male and Female Hartley-Derived Guinea Pigs After Inhalation Exposure to Sulfolane for 27 Days[a]

Parameter[c]		Exposure Group, mg/m^3 (Adjusted Daily Concentration, mg/m^3)[b]	
		0[d]	495 (120)
Number of animals[e]		DNP	15
White blood cell count (10^3/mL)	Preexposure	ND	5.9 ± 0.5
	Postexposure (~30 d)	5.8 ± 0.8	4.9 ± 0.3
Hematocrit count (% by volume)	Preexposure	ND	46 ± 0.4
	Postexposure (~30 d)	39 ± 4.8	48 ± 0.5
Hemoglobin count (g/100 mL)	Preexposure	ND	13.9 ± 0.1
	Postexposure (~30 d)	12.4 ± 1.5	15.2 ± 0.1

[a]Andersen et al. (1977c).
[b]Concentration is adjusted for continuous exposure 24 hours/day, 7 days/week.
[c]Values expressed as mean ± SE (% of control); % is calculated; male and female data were not reported separately.
[d]Though data for a "control" group is reported in Table 3 of the study, a control group is not mentioned in the methods explanation; it is unclear what this "control" group represents.
[e]Sample sizes reflect those at the origin of study; hematological data were taken from 9−15 subjects.

DNP = data not provided by study authors.
ND = not determined.

Table B.21. Hematological Parameters of Male and Female Hartley-Derived Guinea Pigs After Inhalation Exposure to Sulfolane for 85−110 Days[a]

Parameter[c]		Exposure Group, mg/m^3 (Adjusted Daily Concentration, mg/m^3)[b]					
		0[d]	2.8 (2.7)	4.0 (3.8)	20 (19.2)	159 (152)	200 (192)
Exposure duration (d)		DNP	90	110	95	85	90
Number of animals[e]		DNP	DNP	DNP	DNP	15	15
White blood cell count (10^3/mL)	Preexposure	ND	DNP	DNP	DNP	6.8 ± 0.3 (NA)	5.9 ± 0.6 (NA)
	Exposure Day 20	ND	DNP	DNP	DNP	ND	3.1 ± 0.4 (NA)[g]
	Exposure Day 30	5.8 ± 0.8	DNP	DNP	DNP	6.9 ± 0.2 (119)	3.8 ± 0.4 (66)[g]
	Exposure Day 60	4.6 ± 0.8	DNP	DNP	DNP	6.7 ± 0.3 (146)	5.2 ± 0.3 (113)
	Exposure Day 90[f]	6.2 ± 1.1	DNP	DNP	DNP	6.8 ± 0.3 (110)	4.4 ± 0.2[g] (71)
Hematocrit count (% by volume)	Preexposure	ND	DNP	DNP	DNP	46 ± 0.3 (NA)	44 ± 0.4 (NA)
	Exposure Day 20	ND	DNP	DNP	DNP	ND	49 ± 0.9 (NA)
	Exposure Day 30	39 ± 4.8	DNP	DNP	DNP	46 ± 0.3 (118)	51 ± 0.4 (131)
	Exposure Day 60	46 ± 0.5	DNP	DNP	DNP	47 ± 0.3 (102)	47 ± 0.6 (102)
	Exposure Day 90	46 ± 0.8	DNP	DNP	DNP	46 ± 6.3 (100)	47 ± 1.1 (102)
Hemoglobin count (g/100 mL)	Preexposure	ND	DNP	DNP	DNP	16.0 ± 0.1 (NA)	14.4 ± 0.1 (NA)
	Exposure Day 20	ND	DNP	DNP	DNP	ND	14.9 ± 0.2 (NA)
	Exposure Day 30	12.4 ± 1.5	DNP	DNP	DNP	16.8 ± 0.1 (135)	15.5 ± 0.2 (125)
	Exposure Day 60	14.6 ± 0.2	DNP	DNP	DNP	16.9 ± 0.1 (116)	15.1 ± 0.1 (103)
	Exposure Day 90	14.8 ± 0.2	DNP	DNP	DNP	16.6 ± 0.1 (112)	14.6 ± 0.2 (99)

[a]Andersen et al. (1977d).
[b]Concentration is adjusted for continuous exposure 24 hours/day, 7 days/week.
[c]Values expressed as mean ± SE (% of control); % is calculated; male and female data were not reported separately.
[d]Though data for a "control" group are reported in Table 3 of the study, a control group is not mentioned in the methods explanation; it is unclear what this "control" group represents.
[e]Sample sizes reflect those at the origin of study; hematological data were taken from 9−15 subjects at each dose level.
[f]Except for the 159 mg/m^3 exposure-level, which only lasted for a duration of 85 days; observations were made at 85 days for this group.
[g]Significantly different from control ($p < 0.05$); Student's *t*-test.

DNP = data not provided by study authors.
ND = no data.
NA = not applicable.

APPENDIX C. BMD OUTPUTS

A benchmark dose (BMD) analysis of the male renal effects (hyaline droplet) was not attempted because the dose response was nonmonotonic, and statistical analysis performed for this review indicates that incidence of hyaline droplet in cortical tubules at the highest dose was not statistically significantly different from control by Fisher's exact test (4/10 vs. 9/10, $p = 0.0573$). Finally, the endpoint based on leukocyte findings is more sensitive than the kidney effects.

BMD modeling of total WBC count in female rats was attempted using the available continuous models (polynomial, power, Hill, linear) in EPA's BMD software (Version 2.1.2) consistent with EPA's BMD technical guidance (U.S. EPA, 2000). A benchmark response (BMR) of one standard deviation change from the control mean is selected in the absence of a biological rationale for using an alternative BMR. The BMD analysis resulted in significant lack of fit (goodness-of-fit $p < 0.10$) for all continuous models employing nonconstant (modeled) variance (see Table C.1). The homogeneity variance *p*-value of less than <0.1 indicates that nonconstant variance is the appropriate variance model (and therefore it is inappropriate to assume constant variance for these data). Because all nonconstant variance models exhibited poor global fit to the data, a BMDL is not used as the POD.

Table C.1. Model Predictions for Total White Blood Cell Counts in Female Rats Exposed to Sulfolane in Drinking Water for 13 Weeks[a]

Model	Homogeneity Variance *p*-Value	Goodness-of-Fit *p*-Value[b]	AIC for Fitted Model	BMD_{1SD} (mg/kg-d)	$BMDL_{1SD}$ (mg/kg-d)	Conclusions
Hill (nonconstant variance)	0.036	0.027	112.41	9.26	−999.00	Invalid BMDL *p*-score 4 < 0.1
Linear (nonconstant variance)	0.036	0.008	115.30	190.43	131.06	Lowest AIC *p*-score 4 < 0.1
Polynomial (nonconstant variance)	0.036	0.008	115.30	190.43	131.06	Lowest AIC *p*-score 4 < 0.1 Maximum order beta = 0 β2 = 0 β3 = 0 β4 = 0
Power (nonconstant variance)	0.036	0.008	115.30	190.43	131.06	Lowest AIC *p*-score 4 < 0.1 hit bound (power = 1)

[a]Huntingdon Life Sciences (2001).
[b]Values <0.10 fail to meet conventional goodness-of-fit criteria.
AIC = Akaike's Information Criteria; BMD = benchmark dose; BMDL = lower confidence limit (95%) on the benchmark dose.

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May 21, 2012

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Subject:
ASSESSMENT OF DOSE RESPONSE INFORMATION FOR SULFOLANE

There are three laboratory animal studies that have been used by various parties to derive toxicological reference values for sulfolane. Zhu et al. (1987) was a six-page report published in a Chinese journal entitled Huaxi yike daxue xuebao, (Journal of West China University of Medical Sciences). In this study, a series of experiments were performed. Acute, subchronic (90-day), and chronic (6-month) toxicity testing was performed via the oral route of exposure in mice, white rats, and guinea pigs. Zhu et al. (1987) also performed a developmental toxicity study in mice and several genotoxicity tests. Huntingdon Life Sciences (2001) was a GLP-compliant study in which sulfolane was administered to CD rats (10/sex/group) in drinking water at concentrations of 0, 25, 100, 400, or 1600 mg/L for 13 weeks. All animals were examined for individual signs of general health, body weights, food and water consumption, ophthalmoscopy, functional observation battery, hematology, blood chemistry, organ weights, macropathology, and hisopathology. The Ministry of Health and Welfare Japan (MHWJ, 1999) was a 50-day oral gavage study in Crj:CD(S-D) rats as summarized in Organization for Economic Co-operation and Development ([OECD] 2004). These studies are evaluated below in the context of evaluating existing Reference Doses (RfDs) and similar toxicological reference criteria and deriving the alternative scientifically defensible RfDs from the scientific literature.

Summary of Alternative Scientifically Defensible Reference Doses

ARCADIS, U.S., Inc. (ARCADIS) scientifically evaluated the existing RfDs and equivalent toxicological reference values and found that all existing values had issues that did not allow ARCADIS to endorse any of them. Accordingly, ARCADIS derived chronic and subchronic RfDs in accordance with the best available science and United States Environmental Protection Agency (USEPA) guidance for evaluation of

primary toxicology studies and the derivation of RfDs. The alternative scientifically defensible RfDs are as follows:

Chronic RfD	0.01 mg/kg-day
Subchronic RfD	0.1 mg/kg-day

According to the USEPA, a chronic RfD is: “An estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure for a chronic duration (up to a lifetime) to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It can be derived from a NOAEL, lowest observed adverse effects level (LOAEL), or benchmark dose, with uncertainty factors generally applied to reflect limitations of the data used. Generally used in EPA's noncancer health assessments” (USEPA 2011).

Similarly, according to USEPA, a subchronic RfD is: “An estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure for a subchronic duration (up to 10% of average lifespan) to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It can be derived from a NOAEL, LOAEL, or benchmark dose, with uncertainty factors generally applied to reflect limitations of the data used. Generally used in EPA's noncancer health assessments” (USEPA, 2011).

Accordingly, a subchronic RfD is applicable for human health risk assessments involving exposure durations of up to 7 years, which is 10% of an average human lifetime of 70 years. A chronic RfD is applicable for risk assessments involving exposures that exceed 7 years in duration.

USEPA and certain regulatory agencies derive RfDs, not the Agency for Toxic Substances and Disease Registry (ATSDR). Instead, ATSDR derived “public health action levels” for sulfolane using similar procedures as USEPA uses to derive RfDs. The difference between USEPA and ATSDR actions is that USEPA RfDs and State regulatory agency RfDs are toxicological reference values that have regulatory standing and must be used to assess human health risks when performing site specific risk assessments. ATSDR’s public action levels no not have regulatory standing as noted in ATSDR documents.

“The public health action level is a non-regulatory level set to identify if human exposure to that water needs to be evaluated further (a/k/a, a screening level). If exposure is occurring, then consideration should be given to reducing that exposure.” (ATSDR 2010)

“The public health action level is a non-regulatory level set to identify whether human exposure needs further evaluation.” (ATSDR 2011)

"A public health action level is a recommended, but not required (i.e., non-regulatory), level above which a public health intervention might be needed. Public health interventions are actions taken to reduce further chemical exposure, such as switching to another drinking water source. An action level can be used as a screening tool, because water concentrations of a chemical (contaminant) below that amount do not pose a public health concern." (ADHSS 2012)

"The ATSDR action level is a screening level, and not a clear line between safe and unsafe. It is used as a first step to identify potential contaminants of public health importance for further detailed evaluation, and is therefore set approximately 1,000 times lower than levels that caused health effects in animals. (ADHSS 2012)

The evaluation of existing RfDs, ATSDR toxicological reference values, and the derivation of the alternative scientifically defensible RfDs are described below.

Brief Summary of Existing Screening Values for Sulfolane

Three animal studies are available for consideration in deriving toxicological screening values for sulfolane. Huntingdon Life Sciences (HLS 2001) was a fully documented 90-day oral drinking water study in CD rats that was performed in accordance with Good Laboratory Practices (GLP) with detailed information on each animal. Ministry of Health and Welfare Japan (MHWJ 1999) was a 50-day oral gavage study in Crj:CD(S-D) rats as summarized in OECD (2004). Zhu, et al. (1987) was a 180-day unspecified oral study in unspecified guinea pigs. The results of Zhu, et al. (1987) were published in Chinese in a non peer-reviewed journal with little documentation.

The Canadian Council of Ministers of the Environment (CCME 2006) rejected the Zhu, et al. (1987) study on the basis of study quality and derived a screening value of 0.01 mg/kg-day based on the NOAEL for decreases in white blood cells in rats in the HLS (2001) study, which was 2.9 mg/kg/day, as the Point of Departure. CCME (2006) used a composite Uncertainty Factor of 300 (*i.e.,* Interspecies-10; intraspecies-10; 3 to account for possible teratogenic response at very high doses, subchronic to chronic exposures, and an adequate, but not extensive dataset).

Despite issues of quality, the ATSDR chose the Zhu, et al. (1987) study in its *Health Consultation* for sulfolane as the critical study because it gave a lower Point of Departure than the HLS (2001) study (ATSDR 2011). The ATSDR (2011) derived a screening value of 0.002 mg/kg-day. The Point of Departure was 1.5 mg/kg-day based on benchmark dose modeling of shrinkage of spleen white pulp in guinea pigs as the critical endpoint. The ATSDR (2011) used a composite Uncertainty Factor of 1,000 (*i.e.,* Interspecies-10; intraspecies-10; subchronic-chronic exposure duration-10). Note that the ATSDR (2010) concluded that the Zhu, et al. (1987) six-month duration study (180 day) was a *longer term* duration study that required no subchronic to chronic uncertainty factor, but in 2011, the ATSDR decided, instead, that this 180-day duration study was a *subchronic* duration study that required a subchronic to chronic

uncertainty factor. This decision does not conform to ATSDR's definition of subchronic animal studies, which are studies performed in animals for 30-90 days (ATSDR 2005).

In an update to its March 9, 2011 toxicity factor documentation for sulfolane, the Texas Commission on Environmental Quality (TCEQ 2011a) reviewed screening values presented by ToxStrategies, Inc. (ToxStrategies) and URS Corporation (URS) in a September 6, 2011 document and adopted a screening value of 0.01 mg/kg-day based on a Point of Departure defined as the lower confidence limit on the benchmark dose (BMDL) of 16.1 mg/kg-day based on decreases in white blood cell counts in rats in HLS (2001). The Point of Departure of 16.1 mg/kg-day in rats was first converted to a Human Equivalent Dose (HED) of 3.9 mg/kg-day per USEPA (2011) and TCEQ (2011b). TCEQ (2011a) then used a composite Uncertainty Factor of 300 (*i.e.*, Intraspecies- 10; subchronic to chronic exposures-10; database uncertainty- 3).

In its *Provisional Peer-Reviewed Toxicity Values for Sulfolane (CASRN 126-33-0)*, USEPA (2012a) rejected the Zhu, et al (1987) study on the basis of study quality and derived a Provisional Peer-Reviewed Toxicity Value (PPRTV) of 0.001 mg/kg-day based on the NOAEL for decreases in white blood cells in rats in HLS (2001), which was 2.9 mg/kg/day. They used a composite Uncertainty Factor of 3,000 (*i.e.,* Interspecies-10; intraspecies-10; subchronic to chronic exposures-10; database uncertainty- 3). EPA (2012a) did not use benchmark dose modeling or calculate a HED.

Scientific Critique of Existing Screening Values for Sulfolane

ARCADIS reviewed the existing screening values for sulfolane and determine which value was the most scientifically defensible. ARCADIS finds that the Zhu, et al. (1987) study fails to meet the criteria for an acceptable study established by USEPA, other governmental and nongovernmental bodies, and the Federal Information Quality Act (IQA).

Zhu et al. (1987) was a six-page report published in a Chinese journal entitled Huaxi yike daxue xuebao, (Journal of West China University of Medical Sciences). This journal no longer exists and was subsumed in 2000 by the Journal of Sichuan University (Medical Science Edition). According to OriProbe Information Sciences (2012), the main object of this journal was to present medical and health work performed by students and teachers of the university. There is no evidence on the University's website that this journal is peer-reviewed. Regardless of its peer review status, the report presents an abstract level report of a study with no supporting details.

For instance, the source and purity of the test compound and the analysis of the dosing media were not revealed. The source and strain of animals was not presented. The mode of dosing was not presented, such as drinking water, diet or gavage. It is presumed by ATSDR that the doses were given by gavage, but this most critical of information is not presented in the document. Body weights and water and food consumption were not reported, and no methods for any tests were identified. Most importantly, no individual animal data were presented, and no statistical tests were performed on the white blood cell critical endpoints.

The Zhu et al. (1987) study clearly did not meet the criteria set forth by the USEPA for study selection when deriving RfDs. USEPA's (1994) *Criteria For Assessing The Quality Of Individual Laboratory Animal Toxicity Studies* provides criteria that define the minimum information that must be reported in a study chosen as a critical study for a RfD.

In addition, the Zhu, et al (1987) study does not adhere to the standards of the IQA(Public Law 106-554; H.R. 5658), which requires the Office of Management and Budget (OMB) to issue federal agency-wide guidelines that "provide policy and procedural guidance to Federal agencies for ensuring and maximizing the quality, objectivity, utility, and integrity of information (including statistical information) disseminated by Federal agencies" (Federal Register, Vol. 67, No. 38, February 22, 2002). OMB issued guidelines directing federal agencies, among other things, to: "Issue guidelines ensuring and maximizing the quality, objectivity, utility, and integrity of information (including statistical information) disseminated by the agency, …."

In response, the USEPA developed *Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by the Environmental Protection Agency* (EPA 2002b). In these guidelines, the USEPA expresses a preference for peer-reviewed scientific information as the basis

for human health risk assessment, but the USEPA concedes that not all information available for decision making is peer-reviewed. In that case, the USEPA states that the data must be performed in accordance with an accepted test protocols and Good Laboratory Practices (GLP) so that USEPA scientists can ensure that the study was properly conducted. Zhu, et al. (1987) was not peer reviewed, was not performed in accordance with a standard test guideline, was not performed GLP, nor does it contain sufficient detailed information for any reviewer to ensure that the data are valid.

In 2003, the USEPA also issued *A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information* (USEPA 2003). This document also clearly demonstrates that the USEPA does not rely on studies that have insufficient information for independent review and validation.

Accordingly, the ATSDR (2011) screening criterion cannot be considered to be scientifically defensible, because it is based on the inadequately documented study by Zhu, et al. (1987), which does not conform to USEPA regulations and the IQA. In addition, the USEPA rejected the Zhu, et al. (1987) study as a critical study when deriving PPRTVs (USEPA 2012a).

The screening criteria derived by CCME (2006), TCEQ (2011a) and USEPA (2012a) are all based on the HLS (2001) study. The HLS (2001) study was performed in accordance with GLP criteria. In addition, the HLS (2001) report was a thorough and comprehensive 600 page report with a detailed protocol, a certificate of analysis of the test article, a formulation chemistry report, individual animal signs, body weights, food consumption, and water consumption, individual animal values for ophthalmoscopy, functional observation battery, hematology, blood chemistry, organ weights, macropathology observations and hisopathology observations. The USEPA also sanctioned a peer review of the HLS study, using an independent panel. The screening criteria derived from the HLS (2001) study, thus, deserve due consideration. ARCADIS finds, however, that the values from all three sources (CCME (2006), TCEQ (2011a) and EPA (2012a)), have scientific limitations that do not allow any one of the values to be endorsed.

The CCME (2006) value was based on a simple NOAEL and does not take full advantage of the benchmark dose modeling approach now favored in the United States for derivation of toxicological reference values for human health risk assessment (USEPA 2000).

The TCEQ (2011a) value was based on a value derived by ToxStrategies (2010) with an error corrected in the standard deviation of the white blood cell counts in the female highest dose group. ARCADIS performed benchmark dose modeling and confirmed that the corrected BMDL from the linear model for this endpoint is, indeed, 16.1 mg/kg-day and not 15.1 mg/kg-day as initially stated by ToxStrategies (2010). ToxStrategies (2010) found acceptable and identical model fits for four models (*i.e.,* Exponential M2, exponential M4, linear and power) and chose the results of the linear model, stating that this model was simpler than the other models, citing a USEPA precedent for reliance on the most “parsimonious” model.

ATDSR (2011), however, criticized this decision and stated that when logarithmic dose transformation is performed, the linear and exponential models are equally "parsimonious." ATSDR (2011) further stated: "When the BMDLs are within a factor of three, the lowest AIC [Akaike's Information Criterion] is chosen. Or, if multiple values have the same AIC, then an average is recommended (USEPA 2000)." ARCADIS confirmed that the USEPA's guidance (USEPA 2000) *does* state that it is recommended that the average of BMDL values be taken when multiple models adequately fit the experimental data and multiple BMDLs are within a factor of 3. On the other hand, USEPA (2000) further states that for models "that have met the default statistical criteria for adequacy and visually fit the data, any of them theoretically could be used for determining the BMDL." Thus, ToxStrategies (2010) was not deviating from USEPA (2000) guidance by choosing the linear model over the exponential models. However, the recommendation in USEPA's (2000) guidance is that BMDLs from multiple models with adequate fits can be averaged. Furthermore, a more recent presentation from USEPA stated that BMDLs *can be averaged* in such circumstances, which indicates that EPA is not explictly requiring an averaging approach.

ARCADIS notes that ATSDR (2011) has made several errors when it stated in Tables B-4, B-5, B-6, and B-7 that a particular model was the "best fitting model." In fact, all of the listed models have adequate fits to the experimental data, and in most cases the model fits are *identical.* For instance, the white blood cell data using historical controls provided BMDLs ranging from 5.54 to 16.12 mg/kg-day, and all five models (exponential M2, exponential M4, linear, power and polynomial) gave identical homogeneity variance p-values, goodness of fit p-values, and AIC values. Further, even though all four models met the scaled residual criterion of absolute value <2, the scaled residuals for the linear, power, and polynomial models showed a slightly better fit to the data than the two exponential models (M2 and M4).

ToxStrategies (2010) based its screening value on the white blood cell decrements as a critical endpoint. ARCADIS confirmed that benchmark dose modeling of decrements in lymphocytes yields slightly higher BMDLs. ARCADIS verified the white blood cell benchmark dose modeling of ToxStrategies (2011), specifically, the female rat BMDL values for the white blood cell decrements using the historical control variance are 8.78, 5.55, 16.12 and 16.12 mg/kg-day, for each of 4 BMD model types, with an average BMDL of 11.64 mg/kg-day. All models are acceptable fits to the experimental data, and the AIC values for the four models are identical. Thus, the USEPA's default averaging approach is appropriate for setting a Point of Departure.

The female rat BMDL values for the lymphocyte decrements using the historical control variance are 7.94, 4.37, 15.95, 15.95 and 15.95 mg/kg-day, for each of 5 BMD model types, with an average BMDL of 12.03 mg/kg-day. All five models (including the polynomial model) are acceptable fits to the experimental data. The AIC values for the five models are 102.5, 102.5, 102.6, 102.6, and 102.6. According to USEPA's Benchmark Dose Software manual (EPA 2012b), one model is preferred over another only if "the AIC value is substantially smaller for one model." Clearly, 102.5 is not "substantially smaller" than 102.6, so these AICs are virtually identical. Thus, USEPA's default averaging approach is appropriate for setting a Point of Departure. To summarize, the four model average Point of Departure based on white blood cell

decrements is 11.64 mg/kg-day and the five model average Point of Departure based on lymphocyte decrements is 12.03 mg/kg-day.

The USEPA (2012a) value was based on a simple NOAEL and does not take full advantage of the benchmark dose modeling approach now favored in the United States (USEPA 2000) for derivation of toxicological reference values for human health risk assessment. The USEPA (2012a) performed some initial benchmark dose modeling without log transforming the data as did ToxStrategies (2011) and ATSDR (2011). Without log transforming the data, acceptable model fits were not attained. This outcome was already reported by others, and it is unclear why the USEPA presented the unsuccessful benchmark dose modeling efforts and then did not proceed to log transform the data as did others.

ARCADIS investigated the scientific appropriateness of log transforming data during benchmark dose modeling. Log transformation of the data is explicitly allowed by USEPA guidance (USEPA 1995; 2000; 2012a,b,c). For instance, USEPA (1995) states: "…it may be necessary to transform continuous data in some cases so that they better satisfy the assumptions of a normal distribution. A log-transform is often used for this purpose." Similarly, when discussing acceptable adjustments to the data in the Benchmark Dose (BMD) Methodology Software Tutorial, USEPA (2012c) states: "In certain cases, the typical models for a standard study design cannot be used with the observed data as, for example, when the data are not monotonic, or when the response rises abruptly after some lower doses that give only the background response. In these cases, adjustments to the data (e.g., a log-transformation of dose) or the model (e.g., adjustments for unrelated deaths) may be necessary."

More importantly, the USEPA itself has log transformed data sets when performing benchmark dose modeling. In the IRIS profile for benzene for instance, USEPA (2012d) states: "Most of the data were supralinear (i.e., the magnitude of the reductions in lymphocyte count decreased with increasing unit dose), and it was necessary to transform the dose data according to the formula d' = ln(d+1) in order to fit the available models." This regulatory precedent for log dose transformation concerns a data set that matches the data set for sulfolane. In both cases, the critical effect was decreased white blood cell counts, and in both cases simple log transformation of the raw data provided acceptable model fits.

In addition, ARCADIS reviewed the USEPA's database of Provisional Peer-Reviewed Toxicity Values (PPRTVs) and found that USEPA has derived a total of 44 chronic oral RfDs and 33 chronic reference concentrations. Of the 77 total noncancer toxicity values, 26 are based on benchmark dose modeled values (~33%) with 9 of the 26 (35%) based on a lognormal transformation of the dose-response data from the critical study.

Lastly, log dose transformation is performed in peer-reviewed scientific studies in which reference doses and reference concentrations were derived by benchmark dose modeling of data of critical effects (TERA 2005; Budtz-Jorgensen et al., 2000; Grandjean et al. 1997; Suwazono et al. 2006, 2011; Gaylor et al. 1998; Clewell et al. 2003).

Derivation of Alternative Reference Doses

Based on the above logic, a scientifically defensible approach to deriving chronic and subchronic RfDs for sulfolane is as follows:

1. Based on a quality assessment, the HLS (2001) is defined as the critical study (USEPA, 1994, 2002a, 2002b, 2003, 2012a; Klimisch et al. 1997).

2. The HLS (2001) data are subjected to benchmark dose modeling to define the $BMDL_{10}$ per USEPA guidance (USEPA, 1995, 2000, 2002, 2012a,b).

3. Benchmark dose modeling is performed using log transformed doses per USEPA guidance (USEPA, 1995, 2000, 2012a,b,c;) and in accordance with USEPA's RfC for benzene (USEPA, 2012d). The appropriateness of log transformation of doses is supported by peer-reviewed literature citations (TERA, 2005; Budtz-Jorgensen et al. 2000; Grandjean et al., 1997; Suwazono et al., 2006, 2011; Gaylor et al., 1998; Clewell et al., 2003).

4. Benchmark dose modeling is performed using historical control variances per USEPA guidance (USEPA 1994; 2000 2012b).

5. White blood cell reduction is defined as the critical endpoint instead of lymphocyte reduction because benchmark dose modeling of white blood cell data results in slightly lower BMDLs. USEPA (2012a), TCEQ (2011a), and CCME (2006) all based their screening criteria on decreases in white blood cells in rats as reported by HLS (2001).

6. Because the exponential M2, exponential M4, linear, and power models all provide acceptable fits to the experimental data and because no model has a "substantially lower" AIC value, EPA's default approach of averaging the BMDLs and designating the four model average BMDL as the Point of Departure is used (EPA 2000).

7. The four model average BMDL is 11.64 mg/kg-day for white blood cells (12.03 mg/kg-day for lymphocytes). Thus, the Point of Departure is defined as 11.64 mg/kg-day.

8. The chronic RfD is derived from the Point of Departure using a standard composite Uncertainty Factor of 1,000 (Interspecies-10; intraspecies-10; subchronic to chronic exposures-10).

The interspecies UF of 10 is a standard UF unless one converts the animal dose to a Human Equivalent Dose (HED). In that case, the HED conversion is considered by EPA to comprise the pharmacokinetic portion of the interspecies UF, and only the pharmacodynamic portion of that UF is used (1-3). In this case, the standard UF of 10 is used to be consistent with the approaches taken by EPA (2012a), ATSDR

(2011), and CCME (2006). If the HED were calculated and then the maximum pharmacodynamic UF of 3 applied, the total effect would be to reduce the chronic RfD from 0.012 to 0.01 and the subchronic RfD from 0.12 to 0.1 mg/kg-day. TCEQ (2011a) used an interspecies UF of 1 after converting the animal dose to an HED.

The intraspecies UF of 10 is a standard UF used by USEPA (2012a), ATSDR (2011), CCME (2006) and TCEQ (2011a).

The subchronic to chronic UF of 10 is a standard UF used by USEPA (2012a), ATSDR (2011), CCME (2006) and TCEQ (2011a).

Because the database is adequate for setting RfDs, a database uncertainty factor of 1 was used.

The composite UF of 1,000 is the same composite UF as used by ATSDR (2011). It is higher than the composite UFs of TCEQ (2011a) and CCME (2006), which were both 300. Lastly, is it slightly lower than the composite UF used by USEPA (2012a). Thus, the composite UF is within the range of UFs used by others.

9. The subchronic RfD is derived from the Point of Departure using a standard composite Uncertainty Factor of 100 (Interspecies-10; intraspecies-10). The subchronic RfD is 0.12 mg/kg-day, rounded to 0.1 mg/kg-day. The UFs are as noted above with the omission of the subchronic to chronic UF, which is unnecessary for subchronic exposures.

10. The chronic RfD is 0.012 mg/kg-day, rounded to 0.01 mg/kg-day.

11. The chronic RfD is virtually identical to the TCEQ (2011a) value (0.013 mg/kg-day) and the CCME (2006) value (0.010 mg/kg-day), although the values are derived using different approaches.

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Drinking Water Guidance Value for Sulfolane

A health-based Drinking Water Guidance Value of 0.04 mg/L (40 µg/L) is established for sulfolane, based on lifetime exposure. Occasional short-term exceedances above this value are not considered to be of concern. For more significant, long-term exceedances that cannot be addressed through treatment, it is suggested that a plan be developed and implemented to address these situations.

Health Canada can develop a Drinking Water Guidance Value (DWGV) at the request of a federal department, a province or a territory. This DWGV has been established for the Alberta Department of Environment and Sustainable Resource Development. It is based on limited scientific information available at the time of the request, and not on a thorough research of all existing studies.

DWGVs are not subject to a review as thorough as the *Guidelines for Canadian Drinking Water Quality*, which undergo internal peer review and public consultation before being approved by the Federal-Provincial-Territorial Committees on Drinking Water and on Health and the Environment. DWGVs apply to water intended for human consumption, and do not replace or supersede existing guidelines or regulations in place.

Background Information

Identity, use and sources

Sulfolane ($C_4H_8SO_2$; CAS 126-33-0) is a solvent used for gas treating in a variety of industrial processes. It is known under a variety of synonyms and trade names, including bondelane A, 2,3,4,5-tetrahydrothiophene-1,1-dioxide, and tetramethylene sulfone. It has a molecular weight of 120.17 g/mol, a density of 1.276 $g \cdot cm^{-3}$ at 15°C, an aqueous solubility of 1,266,000 mg/L at 20°C, a log Kow of -0.4, a vapour pressure at 20°C of 1.33 × 10-3 kPa, and a Henry's law constant of 4.6×10^{-6} $atm \cdot m^3 \cdot mol^{-1}$. Sulfolane is poorly adsorbed to soil, has a high aqueous solubility, low volatility and is highly mobile in the subsurface. Under typical groundwater conditions, sulfolane degradation may be slow or non-existent. However, under conditions of typical surface water, sulfolane degradation is relatively rapid, with complete removal occurring after 5 to 11 weeks (CCME, 2006).

Exposure

The total worldwide production of sulfolane is estimated at between 18,000 and 36,000 tons per year. Reports on the presence of anthropogenic sulfolane in the North American environment are limited to data collected in the vicinity of gas processing facilities in Alaska (U.S.) and in Western Canada; the maximum measured sulfolane concentrations in groundwater were 800 mg/L in shallow till and 88 mg/L in bedrock (CCME, 2006). Testing of 28 monitoring wells at a North Pole refinery reported sulfolane concentrations ranging from 21 to 6,520 µg/L (Arcadis U.S. Inc., 2013). Sulfolane concentrations in private wells near the refinery ranged from 40 to 415 µg/L (Barr Engineering Company, 2013).

Multi-route exposure assessment

To assess the overall exposure of sulfolane in drinking water, the relative contribution of each exposure route was assessed through a multi-route exposure assessment approach (Krishnan and Carrier, 2008). Both the dermal and inhalation routes of exposure during bathing or showering are considered significant if they contribute to at least 10% of the drinking water consumption level. On the basis of the estimated skin permeability coefficients and the air to water concentration values, it was found that dermal and inhalation exposures through showering or bathing were not significant.

Kinetics

Sulfolane is well absorbed through the oral route but not through human skin. Sulfolane rapidly distributes throughout the body and is removed from plasma with a half-life of 3.5 to 5.0 hours in test animals. When 100 mg of sulfolane was administered intraperitoneal to rats, 85% of the sulfolane was excreted in urine as a metabolite, 3-hydroxy sulfolane, in the first 24 hours (ATSDR, 2010).

Toxicological Information

No studies were identified on the effects of oral or inhalation exposures of sulfolane in humans. No carcinogenicity studies of animals orally exposed to sulfolane have been identified and there is no evidence to suggest that sulfolane is genotoxic (CCME, 2006; ATSDR, 2010; NCEA, 2012). In animals, studies have found decreased total white blood cell (WBC) count as well as kidney and spleen effects. These studies are described below.

In a single published study that was translated to English from Chinese, Zhu et al. (1987) conducted a series of studies on the acute, subchronic (90-day) and chronic (6-month) oral toxicity of sulfolane in mice, white rats, and guinea pigs (studies summarized below). Study authors also conducted a developmental study (discussed below) and several negative genotoxicity tests (Ames, bone marrow micronucleus test, and sister chromatid exchange test). The study authors did not state whether the experiment adhered to GLP guidelines and data tables were not provided in the translation. This report appears to be an extended abstract of the original study and its use is limited for risk assessment purposes. For example, there is no clear indication of histopathological examination of any tissues in any test described, except for the spleen and liver in the 6-month study. Exposure type (e.g., gavage, drinking water, diet) and frequency of oral administration were not reported. The study authors did not delineate the specific biochemical parameters examined, nor did they specify the meaning of "liver biochemical index." Further, statistical testing is poorly reported. However, since studies on sulfolane toxicity are limited, and based on the fact that this study was used by ATSDR as a key study it is summarized below.

Subchronic toxicity

Huntingdon Life Sciences (HLS, 2001): A good laboratory practice (GLP)-certified subchronic (90 day) drinking water study for sulfolane in CD rats was conducted. Although this study was funded by industry and it is not publicly available, ATSDR obtained the data and extensive summaries are available in several independent reports (CCME. 2006; ATSDR, 2010; NCEA, 2012). Rats (10/sex/group) were exposed to concentrations of 0, 25, 100, 400 or 1600 mg

sulfolane/L drinking water *ad libitum* (estimated daily doses of 2.1, 8.8, 35 and 132 mg/kg bw per day in male rats and 2.9, 10.6, 42 and 191 mg/kg bw per day in female rats). A thorough examination of effects included: food and water consumption, bodyweight, organ weights, functional observations (e.g., reflexes, grooming, motor activity), hematological evaluations, blood chemistry, gross pathology and histopathological examination of: adrenals, brain, femur, heart, ileum, kidneys, liver, lungs, mammary area, spinal cord, stomach, thyroid and uterus.

The exposure was described as well tolerated, and the study authors identified two primary effects of concern. First, male renal toxicity involving inhibition of α-2μ-globulin that is probably not relevant to humans for purposes of risk assessment (Dellarco and Baetcke, 2005). Secondly, the most relevant effect considered to be treatment-related by the HLS study authors was a decrease in lymphocyte, monocyte and large unstained cell counts, as well as a concomitant decrease in total leukocyte or WBC counts in female rats administered 100, 400 or 1600 mg/L (10.6, 42 and 191 mg/kg bw per day). Males did not experience similar decreases in these cell counts. Although there was no assay of functional manifestation of the white cell decreases such as compromised immune function, the decreases in WBC counts seen in female rats were broad (seen in several cell types), statistically significant and dose related. Additionally, there was a statistically significant decrease in the spleen weights at the high dose, which supports the immune suppression effect; this effect was reported in other studies of sulfolane exposures (albeit at higher exposures) in a different rat strain (Crj:CD[S-D]) and other species (guinea pigs; Zhu et al., 1987). A lowest observed adverse effect level (LOAEL) of 10.6 mg/kg bw per day and a no observed adverse effect level (NOAEL) of 2.9 mg/kg bw per day were identified in female rats, based on statistically significant decreases in total WBCs, lymphocyte, monocyte and basophil counts.

Ministry of Health and Welfare Japan (1996): In a GLP-compliant, peer-reviewed study, sulfolane was administered by gavage to 5-week old male and female Crj:CD(S-D) rats at dose levels of 0, 60, 200, or 700 mg/kg bw per day for 28 days. While written in Japanese, the study was reviewed and reported by the Organisation for Economic Cooperation and Development (OECD, 2004). There were 6 animals/sex in the 60 and 200 mg/kg bw per day groups and 12 animals/sex for the groups dosed at 0 and 700 mg/kg bw per day. After 28 days of treatment, 6 animals in the control and 6 in the 700 mg/kg bw per day groups were observed for a 14-day recovery period. The exact methods, animal husbandry, and statistical procedures performed by the Ministry of Health and Welfare Japan were not reported by the OECD.

There were no deaths in the control or treatment groups. Males in the 700 mg/kg bw per day group experienced significantly ($p < 0.01$) lower absolute body weight compared with controls throughout treatment (12−14% bodyweight depression from days 3−28), while high-dose females only showed significant differences ($p < 0.01$) from controls for the first 14 days of treatment (11% absolute body-weight depression only on day 3). High-dose males experienced significant ($p = 0.01$) decreased food consumption for the first 3 weeks of treatment, while females had significant ($p < 0.01$) decreased food consumption the first week of treatment. High-dose females experienced decreased locomotor activity (3/12 animals) during the beginning of the treatment period. Hematology revealed that all dosed male groups had significant ($p = 0.05$) slightly decreased (2−3%) mean cell hemoglobin concentration after 28 days of treatment, but there was no decrease observed after the 14-day recovery period. Males of the high-dose group

had significant ($p = 0.05$) higher WBC counts compared with control only after the recovery period and not after the 28-day treatment period. Because only the control and the high-dose groups were examined after recovery, a dose-response relationship could not be evaluated. Effects on WBCs in treated females were not observed. High-dose females had significant reduced mean red blood cell counts and significant increased mean cell volume compared with controls after recovery ($p = 0.01$). The high-dose females had elevated ALT (46% above control) and decreased glucose (15% below control). High-dose male rats experienced significant increased ($p = 0.05$) relative kidney, brain and heart weight, and increased incidence and severity of hyaline droplets and eosinophilic bodies in the renal tubules at both 200 and 700 mg/kg bw per day. Based on observed kidney effects in male rats, a LOAEL of 200 mg/kg bw per day and a NOAEL of 60 mg/kg bw per day were identified, however as noted above, this effect is likely related to α-2μ-globulin and likely not relevant for human risk assessment.

Subchronic study (Zhu et al., 1987): 80 white rats and 80 guinea pigs (sex, age, strain not specified) where given 0, 55.6, 167, or 500 mg/kg-day sulfolane for 90 days, after which the animals were sacrificed. In guinea pigs, WBC counts were significantly ($p < 0.05$) decreased relative to controls values in all dose groups, although no other indication of dose response was described or given. In rats, no significant changes in biochemical parameters or pathology were reported in the low- and mid-dose groups. However, the study authors reported significant changes in the high-dose group (500 mg/kg bw per day) including changes in urine volume, increased gamma glutamyl transferase activity in the urine, decreased serum alkaline phosphatase activity, decreased ICD (undefined in the study report) and decreased thrombin. The study authors stated that other examined parameters did not exhibit statistically significant changes. The authors concluded that sulfolane affects the blood system, liver and kidneys and that guinea pigs are more sensitive than rats.

Subchronic/chronic toxicity

Zhu et al. (1987): Guinea pigs (20/sex/dose) were orally dosed with sulfolane at dose levels of 0, 0.25, 2.5, 25, or 250 mg/kg bw per day for 6 months. Biochemical and pathological evaluations were conducted on a subset of animals during an interim sacrifice at 3 months (subchronic) and at the end of the study at 6 months (chronic). The translation did not state the specific biochemical parameters, organs examined, or whether the pathology mentioned was gross pathology or histopathological. At the 3-month interim sacrifice, levels of ALT, AST and marrow cell number were lower than controls but statistical significance was not reported. Incidence of shrinkage of white pulp in the spleen in the 0, 0.25, 2.5, 25, and 250 mg/kg bw per day groups were reported as 0/14, 0/14, 1/14, 2/14 and 6/14, respectively (no statistical analysis reported). At 6 months, a "liver biochemical index" for male guinea pig was 40.2 and significantly different from the control group, but this term was undefined. A dose-response relationship in the increased incidence of fatty deposits in the liver was reported as 0/25, 0/22, 2/26, 4/25, and 7/22 and then again as changes in fatty liver deposits at 2.5 mg/kg bw per day (1/26), 25 mg/kg bw per day (2/25) and 250 mg/kg bw per day (5/22). Likewise, shrinkage of splenic white pulp was reported: 2/26 at 2.5 mg/kg bw per day, 2/25 at 25 mg/kg bw per day, and 7/22 at 250 mg/kg-day. Based on these reported histopathological results, a no-effect of 0.25 mg/kg bw per day and a chronic threshold of 2.5 mg/kg bw per day were reported.

Reproduction and Development

Zhu et al. (1987): female Chinese Kunming mice (number not reported) were orally administered sulfolane in distilled water at dose levels of 0, 93, 280, or 840 mg/kg bw per day on gestational days (GDs) 6−15. A positive control (*N*',*N*-methylene-bis-2-amino-5-sulfhydryl-1,3,4-thiadianole) and negative control (distilled water) were also administered to pregnant mice. On GD 18, fetuses were removed and examined for abnormalities. The study authors provided no other experimental details or methods of statistical analysis. In the highest dose group (840 mg/kg bw per day) the incidence of skeletal abnormalities was significantly higher ($p < 0.01$) than the negative control and the number of fetal resorptions increased compared to negative control (30.16% versus 13.53%, respectively), but statistical significance was not specified. No skeletal abnormalities were observed in pups in the 280 mg/kg bw per day group. Data from the study indicate a developmental NOAEL of 280 mg/kg bw per day and corresponding LOAEL of 840 mg/kg bw per day. Although study authors did not indicate whether GLP was followed, the study is considered acceptable because both skeletal and visceral observations of the pups were made and abnormalities in pups were detected after treatment with sulfolane.

The Ministry of Health and Welfare Japan (1999): This Japanese one-generation reproductive/ developmental toxicity screening test was peer-reviewed by OECD (2004), who also provided an English summary and data tables. The study followed OECD 421 guidelines and was conducted under GLP standards. Study authors administered sulfolane in water by gavage to 10-week-old Crj:CD(S-D) rats (12/sex/group) at doses of 0, 60, 200, or 700 mg/kg bw per day for 41−50 days. The dosing period extended from 14 days before mating to lactation day 3. Study authors recorded the following parameters: number of successful copulated pairs, copulation index, paring days until copulation, number of pregnant females, fertility index, number of corpora lutea, number of implantation sites, implantation index, number of living pregnant females, number of pregnant females with parturition, gestation length, number of pregnant females with live pups on Day 0, gestation index, number of pregnant females with live pups on Day 4, delivery index, number of pups alive on Day 0 of lactation, live birth index, sex ratio, number of pups alive on Day 4 of lactation, viability index and body weight of live pups (on Days 0 and 4). At necropsy, study authors collected organ weights in the parental generation for testes, epididymides, and ovaries. Microscopic examinations of these organs were conducted for animals in the high-dose group only. Pups were examined macroscopically but did not include a detailed organ or skeletal examination. In females of the 700 mg/kg bw per day dose group, fewer estrous cycles, a significant ($p < 0.01$) increase in stillbirths, increased relative ovary weight at necropsy and a significant ($p < 0.01$) decrease in birth index, live birth index, and number of pups were reported. Females dosed with 200 mg/kg bw per day had a significant ($p < 0.05$) decrease in delivery and birth indices. Mean pup weight was significantly decreased on lactation day 0 and 4 in the 700 mg/kg bw per day group ($p < 0.01$). Mean litter weights were significantly decreased ($p < 0.05$) compared to control at ≥200 mg/kg bw per day. No external anomalies were observed in any of the treated pups at necropsy. Based on decreased delivery and birth indexes, a NOAEL of 60 mg/kg bw per day an a LOAEL of 200 mg/kg bw per day were identified for reproductive and developmental toxicity.

Treatment Technology

There is limited information available in the literature for the removal of sulfolane from water supplies. Available bench-scale and pilot-scale data reported that filtration with granular activated carbon was effective in reducing sulfolane at the residential scale and in small systems.

Municipal Scale

Based on the information and testing for residential scale systems described below, municipal scale treatment of sulfolane is expected to be achievable using granular activated carbon (GAC) technology. Following the studies conducted by the Barr Engineering Company (2013) described below, the Drinking Water Program within the Alaska Department of Environmental Conservation (DEC) has granted approval to operate GAC sulfolane treatment systems at two Public Water Systems (Alaska Department of Environmental Conservation, 2014).

Residential Scale

The Barr Engineering Company (2013) conducted a number of studies on sulfolane, as described below.

Screening-level testing of residential treatment technologies was conducted at a contaminated site in North Pole, Alaska to evaluate: potassium permanganate; calcium hypochlorite; ultraviolet radiation (UV oxidation); hydrogen peroxide (H_2O_2); H_2O_2 + UV oxidation; and activated carbon adsorption. Results indicated that activated carbon adsorption showed the most promise for a potential point-of-entry (POE) residential system and that H_2O_2 + UV oxidation showed limited removal capacity.

Follow-up feasibility studies were conducted at bench-scale for advanced oxidation processes (AOPs) using H_2O_2 + ozone and H_2O_2 + UV oxidation and at both bench- and pilot-scale for activated carbon. They found that AOPs using H_2O_2 + ozone and H_2O_2 + UV oxidation, regardless of configuration or combinations of technologies, were not effective at removing sulfolane in drinking water (less than 40% reduction). The bench-scale study for carbon adsorption was conducted using feed water supplied via a 500-gallon tank, containing sulfolane concentrations ranging from 310 to 350 µg/L (average of 320 µg/L); TOC concentrations ranging from 2 to 3 mg/L; iron concentrations below 50 µg/L; manganese concentrations of approximately 1 µg/L; alkalinity of approximately 200 mg/L as $CaCO_3$; pH values between 7 and 8; and water temperature was maintained between 4 and 7°C. Samples were collected at the influent and effluent sampling points of each of 3 columns (in parallel) every 60 minutes for the 150 hour-duration of the test. An Empty Bed Contact Time (EBCT) of 4 min resulted in a time to breakthrough 66 hours for the first column, at a loading rate of 0.3 gpm (approximately 7,000 gallons/ft^3 of activated carbon). The bench-scale data showed that carbon adsorption was very effective for the treatment of sulfolane in drinking water, achieving at least 97% removal prior to breakthrough.

Pilot testing was undertaken to ensure that the treatment design was adequate for use at full residential scale on a variety of water sources to the clean-up level of 14 µg/L established by the Alaska Department of Environmental Conservation (DEC). Both accelerated and in-home pilot testing were undertaken in the study. The accelerated pilot test trials were conducted on a full-scale POE treatment system design of two primary 2.5-cubic-foot GAC vessels operating in

series at a loading rate of 3 gpm through one vessel (equivalent to two vessels in parallel at 6 gpm) using two different flow regimes. The first trial consisted of a constant flow with no downtime, while the second trial used a "50:50" flow scenario (20 min on and 20 min off for 16 hours, followed by eight hours of completely off)

In the first trial (constant flow), the influent concentration varied between 156 and 235 µg/L and the first detectable level of sulfolane in the first vessel effluent was seen after treatment of 10,739 gallons. In the second trial (50:50 flow scenario), the influent sulfolane concentration varied from 231 to 290 µg/L and the first detectable level of sulfolane in the first vessel effluent was seen after treatment of 11,794 gallons. The sulfolane concentration in the first vessel effluent showed minimal increase following breakthrough as the trial continued. The testing results of the accelerated pilot testing confirmed successful sulfolane removal through a POE treatment system with GAC, achieving sulfolane concentrations below the reporting limit of 10 µg/L or the detection limit of 3.1 µg/L prior to breakthrough.

In-home pilot testing was also undertaken at five selected residences using one or two 2.5-cubic-foot GAC vessels for the purposes of evaluating sulfolane breakthrough. The test homes were selected to include both higher and lower sulfolane concentrations and to provide a range of anticipated water qualities for the residences where installation of the full-scale systems was planned. Average concentrations of sulfolane varied between 36.3 and 403 µg/L. Weekly sampling included measurement of the water usage rate, collection of sulfolane samples from the feed to and effluent from the first GAC vessels. Measurements of iron, manganese, TOC, oxidation-reduction potential (ORP) and fecal coliforms were conducted weekly. The study included two types of POE treatment systems: (1) a two-vessel design consisting of first and second vessels plumbed in series followed by a third vessel for redundancy, which was installed at 3 locations and tested between November 2010 and November 2011; and (2) a single-vessel design consisting of a first vessel followed by a second vessel for redundancy, which was installed at 2 locations and tested between November 2010 and June 2011. All sulfolane concentrations were below10 µg/L prior to breakthrough in the first vessel and there was no detection of sulfolane in any of the subsequent (redundant) vessels.

Further to this in-home pilot study, the Water Quality Association (WQA) certified the single unit (simplex) 2.5-cubic-foot GAC vessel as capable of treating sulfolane to levels below 10 µg/L at a flow rate of 3 gpm. The certification treatment conditions are as follows: 25,000 gallons of water at an influent sulfolane concentration of 55 µg/L; 14,900 gallons at an influent sulfolane concentration of 155 µg/L; and 10,000 gallons at an influent sulfolane concentration of 350 µg/L. As such, any water with greater than 350 µg/L of sulfolane will require either remediation prior to treatment or pilot testing of other designs to ensure that they are capable of removing higher concentrations of sulfolane.

The report (Barr Engineering Company, 2013) concluded that the majority of homes where the POE treatment would be used have sulfolane concentrations below 100 µg/L, thus a standard 2.5-cubic-foot residential GAC vessel could last much longer than three months in those cases. It also found that the scale of the required GAC equipment provides sufficient capacity and redundancy for a residential setting.

Classification and Rationale

Currently, there are no epidemiological studies or other data that support the carcinogenicity of sulfolane in humans and no evidence of genotoxicity. The most acceptable study to use for deriving an oral reference value is a GLP compliant, peer-reviewed study (HLS, 2001) that identified statistically significant decreases in the total WBC and lymphocyte counts in female rats exposed to sulfolane in drinking water for 13 weeks. Although alternative studies are available (i.e., Zhu et al., 1987; Ministry of Health and Welfare Japan, 1996), they were originally published in a foreign language and the available translations do not contain detailed documentation of experimental methods and study design. By comparison, the HLS (2001) study authors conducted the drinking water study at a lower dose range and examined a wide array of endpoints.

Calculation of Health Canada's Drinking Water Guidance Value (DWGV)

The benchmark dose (BMD) approach is an alternative to the NOAEL/LOAEL approach that has been used for many years and by many international agencies (including the U.S. EPA and OECD) in dose-response assessment. The BMD approach is preferred in this assessment because of the recognized limitations in the NOAEL/LOAEL approach, and the key advantages BMD offers over the NOAEL approach, including using all experimental data (which reflects the dose-response relationship to a greater degree and is less dependent on study size), being independent of predefined dose levels and spacing of dose levels, and allowing the calculation of the magnitude of any effect within the observable range.

BMD modeling of total WBC and lymphocyte counts using historical and concurrent control HLS (2001) datasets from female rats resulted in the lowest $BMDL_{1SD}$ of 4.12 mg/kg bw per day (ATSDR, 2011) this value is used as our point of departure.

$$TDI = \frac{BMDL_{1SD}}{UF}$$

$$= \frac{4.12 \text{ mg/kg bw per day}}{1000}$$

$$= 0.00412 \text{ mg/kg bw per day}$$

where:

TDI = tolerable daily intake; the concentration of a chemical that is not expected to pose a risk to human health resulting from daily exposure over a lifetime;

$BMDL_{1SD}$ = For continuous datasets, the benchmark response was set to 1 standard deviation in order to obtain a benchmark dose 95% lower confidence limits ($BMDL_{1SD}$) value of 4.12 mg/kg bw per day for sulfolane which is comparable to a $BMDL_{10}$ (10 % additional risk) for dichotomous datasets; and

UF = uncertainty factor of 1000 is selected as follows: ×10 for interspecies variability, ×10 for intraspecies variability and ×10 for database deficiencies (including use of a subchronic study and lack of appropriate toxicity and epidemiological studies.

Based on the above TDI, a drinking water guidance value (DWGV) is calculated as follows:

$$\text{DWGV} = \frac{\text{TDI} \times \text{BW} \times \text{AF}}{\text{WC}}$$

$$= \frac{0.00412 \text{ mg/kg bw per day} \times 70 \text{ kg} \times 0.2}{1.5 \text{ L}}$$

$$= 0.04 \text{ mg/L (rounded)}$$

where:

BW = body weight; the mean body weight estimated for an adult Canadian is 70 kg;
AF = allocation factor; the proportion of exposure to sulfolane from drinking water, as opposed to other environmental media (i.e., food, air, soil, consumer products). 20% is used as a "floor value" when drinking water is not a major source of exposure (Krishnan and Carrier, 2013);
WC = water consumption; the estimated daily volume of tap water consumed by an adult is 1.5 L.

A DWGV of 0.04 mg/L (40 µg/L) for sulfolane is recommended by Health Canada.

Appendix - International Considerations

There are no regulatory limits for sulfolane in drinking water. The Agency for Toxic Substances and Disease Registry (ATSDR) did perform a Health Consultation on sulfolane for the Alaska Department of Health and Social Services. The ATSDR recommended an oral exposure limit of 70 µg/L (ATSDR, 2011). This limit was based on a provisional health guidance value of 0.002 mg/kg/day resulting from a 1.5 mg/kg bw per day BMDL (dispersion of spleen's white pulp in guinea pigs after subchronic oral exposure (Zhu et al., 1987)) and an uncertainty factor of 1000 (×10 for interspecies variation, ×10 for intraspecies variability and ×10 for using a subchronic study). The ATSDR document was criticized by peer reviewers for the use of the Zhu et. al. (1987) study as the basis for their provisional health value.

The U.S. EPA Superfund Technical Support Center recently released a provisional chronic RfD value for sulfolane of 0.001 mg/kg bw per day based on a NOAEL of 2.9 mg/kg bw per day (reduced WBC counts in female rats; HLS, 2001) and a 3000-fold composite uncertainty factor (× 10 interspecies variation, ×10 intraspecies variation, ×10 for using a subchronic study and ×3 for developmental uncertainty; U.S. EPA, 2012).

The CCME developed a source guidance value for groundwater for sulfolane of 0.09 mg/L. A TDI of 0.0097 mg/kg bw per day was based on a NOAEL of 2.9 mg/kg bw per day (reduced WBC counts in female rats (HLS, 2001)) and an uncertainty factor of 300 (×10 for interspecies variation, ×10 intraspecies variation and ×3 for adequate but not extensive dataset and subchronic extrapolation; CCME, 2006). The British Columbia Ministry of Water, Land and Air protection also developed an ambient water quality guideline for sulfolane that is the same as CCME's (British Columbia, 2003).

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ToxStrategies

Innovative solutions
Sound science

September 8, 2014

Jacqueline Patterson
Toxicology Excellence for Risk Assessment
2300 Montana Avenue, Suite 409
Cincinnati, OH 45211

Subject: Comments related to the independent peer review of sulfolane reference doses

Dear Ms. Patterson:

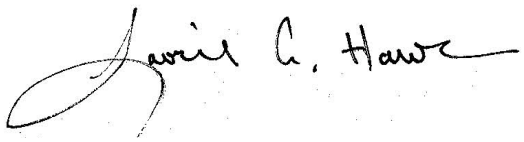
It is our understanding that Toxicology Excellence for Risk Assessment (TERA), on behalf of the Alaska Department of Conservation (ADEC), has convened an independent peer review of the established reference doses (RfDs) for sulfolane and, that as a part of the peer review process, members of the public and scientific community can submit written comments on technical issues for consideration by the panel. ToxStrategies appreciates this opportunity to submit technical comments for consideration by your panel of experts. We will have scientists present both in person, as well as joining via conference call to answer any questions that panel members may have about our analyses and comments.

ToxStrategies scientists have been working to understand the toxicology of sulfolane and implications for risk assessment since the late 2009 timeframe. In 2010, ToxStrategies, working in conjunction with Dr. David Gaylor, developed a scientifically robust reference dose (RfD) for sulfolane based on a state-of-the-science dose-response modeling approach and robust data inputs (ToxStrategies, 2010). Our work ultimately underwent a rigorous scientific peer review and was published in the Journal of Applied Toxicology (Thompson et al., 2013; accepted for publication in June 2012 and published online in August 2012).

We have shared early summaries of our analysis (ToxStrategies, 2010), along with all of the underlying data and modeling runs, with all interested parties (i.e., ADEC, ATSDR, EPA, TCEQ) as they've each proceeded with their own independent processes for developing RfDs. In accordance with the charge questions posed to the panel, we believe that there are a number of key points to take note of concerning the state of the science and the various analyses that have been conducted, including the most recent assessment of the various benchmark dose modeling analyses undertaken by Gradient Corporation on behalf of ADEC (Gradient, 2014). We offer a number of key points for consideration by the panel in our attached comments. Importantly, based on critical review of the Gradient assessment, we have identified a mistake that will impact their conclusions with respect to acceptability of the various models based on the BMD/BMDL ratios. On the whole,

the benchmark dose model verification exercise conducted by Gradient is thorough and consistent with the most recent USEPA BMD practices. However, an apparent error in estimating the BMD/BMDL ratios leads to a substantially different conclusion concerning whether or not all viable model fits have BMD/BMDL ratios <5.0. This is described in detail in our comments (attached) and should be carefully reviewed by the peer reviewers. Dr. David Gaylor, an internationally-recognized expert on BMD modeling and contributor to some of the USEPA Benchmark Dose Modeling Guidance, was asked to independently review the Gradient (2014) report and has confirmed the mistake in the Gradient assessment and offers his own independent thoughts on selection of a POD. His technical comments have been submitted to TERA and have also been included as an attachment to our comments for convenience for the panel.

Sincerely,



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Managing Health Scientist

ToxStrategies

Innovative solutions
Sound science

Comments Offered by ToxStrategies, Inc.
Key Points to Consider as a Part of the Independent Peer Review of Established Reference Doses (RfDs) for Sulfolane

University of Alaska, Fairbanks
September 16-17, 2014

1.0 Zhu et al. (1987) Has Severe Limitations and Should Not Be Used as the Basis for the Sulfolane RfD

USEPA's decision to reject data from the Zhu et al. (1987) study for purposes of developing an RfD is justified. As appropriately characterized by ADEC's contractor (Gradient) in their report issued on August 15, 2014 (Gradient, 2014), numerous investigators have noted substantial deficiencies in the Zhu et al. (1987) study (Arcadis et al., 2012; ATSDR, 2010 and 2011; CCME, 2006; Health Canada, 2014; Magee, 2012; USEPA 2012a; Haney, 2011; Thompson et al., 2013; ToxStrategies, 2010). Overall, there is so little detail about the materials, methods and compliance with accepted research standards for conducting *in vivo* toxicity studies that the quality and accuracy of the results in the Zhu et al. (1987) study is difficult to judge. Examples of some of the specific deficiencies noted in our review of Zhu et al. (1987) are outlined in **Attachment A**. As a result of these limitations/ deficiencies, data from the Zhu et al. (1987) publication should not be used as a basis for the sulfolane RfD, especially given the availability of another high quality study (i.e., subchronic GLP drinking water study conducted by Huntingdon Life Sciences (HLS) (HLS, 2001)).

2.0. Benchmark Dose Modeling is Preferred Over a NOAEL/LOAEL Approach

Because of the limitations of the traditional NOAEL/LOAEL approach (described in more detail in **Attachment B**), USEPA and others involved in dose-response modeling have articulated a strong preference for dose-response data to be modeled whenever feasible as opposed to simply default NOAEL/LOAEL approaches (USEPA, 2000, 2002, and 2012b; EFSA, 2009; Zhao et al., 2010; Davis et al., 2011).

Several groups of investigators have independently demonstrated that the dose-response data from the HLS (2001) study is amenable to BMD modeling (ToxStrategies, 2010; ATSDR, 2011; Thompson et al., 2013; Gradient, 2014) and several regulatory agencies have adopted RfDs based on BMD modeling of the HLS (2001) data (Haney et al., 2011; Health Canada, 2014).

3.0 Log Transformation of Dose was Necessary, Appropriate and Consistent With USEPA Guidance

The USEPA BMD guidelines (2000, 2012b) indicate that transformation of dose can help improve model fits to data. Specifically, USEPA (2012b) states that:

> "*Whenever none of the available models provides an adequate fit to the data…adjustments to the data (e.g., a log-transformation of dose or adjustments for unrelated deaths) may be necessary*."

Several groups have demonstrated that, while no models provided adequate fits based on initial modeling where dose was modeled on an arithmetic scale, log transformation of dose did in fact yield good model fits when applied to the HLS data for white blood cell (WBC) and lymphocyte counts (ToxStrategies, 2010; ATSDR, 2011; Thompson et al., 2013; Gradient, 2014).

4.0 The USEPA IRIS Assessment for Benzene Supports the Use of Log-Dose Transformation and Provides an Important Precedent

USEPA has undertaken one noteworthy IRIS assessment in which log transformation of dose was employed when modeling a continuous endpoint – the noncancer risk assessment of benzene (USEPA, 2002). The endpoint modeled in the USEPA IRIS benzene assessment was blood lymphocyte counts in human workers exposed to benzene. Initial BMD modeling of the lymphocyte data resulted in models with poor fits. After log transformation of dose, suitable model fits were obtained.

The endpoint (lymphocyte count) and modeling approach (log transformation of dose) are highly relevant to the sulfolane data set. Specifically, log transformation of dose was necessary to find suitable BMD model fits for blood lymphocyte and white blood cell (WBC) counts in rats.

In the IRIS assessment of benzene, the USEPA selected the linear model because it was the most parsimonious of the models that fit the lymphocyte data.

Given the similarities in the endpoints and data issues, the USEPA IRIS assessment for benzene establishes an important precedent for how to model the HLS (2001) dataset for sulfolane.

5.0 Use of Historical Control Data is Beneficial and Consistent With USEPA Guidance

The USEPA BMD guidance (2000, 2012b) indicates that use of historical variation data for continuous endpoints can be used if available. USEPA (2012b):

> *"…in the absence of any other idea of what level of response to consider adverse, a change in the mean equal to one control SD from the control mean can be used; if warranted by statistical and biological considerations, a lower or higher increment of the control SD might be used. The control SD can be computed including historical control data, but the control mean should be from data concurrent with the treatments being considered."*

Using historical blood count data has the advantage of providing a more representative estimate of variability in a given parameter due to a much larger sample size (USEPA, 2000). Given the concerns about the biological relevance of the effects on blood cell counts (HLS, 2001), it was deemed preferable to utilize more robust historical control data in the derivation of the BMD/L values. As such, historical control hematology data were obtained for 393 female CD Sprague–Dawley rats of 16–21 weeks of age from HLS and is provided in **Attachment C.** These historical data are ideal because they represent the same species, strain, sex, and age group of animals from the same time period as those in the HLS (2001) study of sulfolane. Moreover, because these data are from the HLS laboratory, the total WBC and lymphocyte counts were most likely obtained using the same collection and analytical techniques as used in the HLS sulfolane study.

One final point is that there is no clear basis for averaging BMDL values based on modeling with concurrent and historical controls as done by Gradient (2014). One should decide either to model with concurrent or historical control data.

6.0 Allometric Scaling Reduces Uncertainty When Extrapolating Across Species

In the absence of physiologically based pharmacokinetic (PBPK) models or evidence of species-specific toxicokinetic differences for a chemical, it is the typical and preferred USEPA practice to employ allometric scaling, specifically bodyweight$^{3/4}$ scaling (USEPA, 2011). This interspecies adjustment (i.e., allometric scaling) was done in Thompson et al. (2013). It should be recognized that this adjustment effectively reduced the POD for sulfolane by 4-fold in rats. This adjustment is slightly greater than (i.e., more conservative) the typical default 3-fold pharmacokinetic interspecies adjustment accounted for in the default interspecies UF of 10 that is applied in some screening level risk assessments (USEPA, 2002). Thus, while Table 2 (pg 10) in the ADEC Background document (ADEC, 2014) lists the composite uncertainty factor (UF) from Thompson et al. (2013) as 300-fold, the total adjustment to the POD, including the application of allometric scaling to scale pharmacokinetics across species, was approximately 1200-fold. As such, the total adjustment applied by Thompson et al. (2013) is exceeded only by USEPA's 3,000-fold UF.

7.0 Mistake in Gradient's BMD/BMDL Ratio Analysis

On the whole, the benchmark dose model verification exercise conducted by Gradient is thorough and consistent with the most recent USEPA BMD practices. However, an apparent

error in estimating the BMD/BMDL ratios leads to a substantially different conclusion concerning whether or not all viable model fits have BMD/BMDL ratios <5.0 and this calls into question the POD recommended by Gradient in Tables 4.1 and 4.2 of their report (Gradient, 2014). Specifically, on page 12 of the Gradient report it is stated that smaller BMD/BMDL ratios indicate stronger confidence in the BMDL estimates It is further noted that "In order to assess the uncertainty from the BMD/BMDL estimates, USEPA applies a default ratio of >5.0", meaning that models should generally have a ratio less than five. In Tables 3.1 to 3.12, Gradient reports the BMD/BMDL ratio for all of the various modeling scenarios. Gradient concludes that all viable models had ratios <5.0—indicating "the BMD modeling results are sufficient to be used for selecting a POD."

However, we have determined that all of the reported ratios in Tables 3.1 to 3.12 are based on the BMD and BMDL values in log space, (i.e., before the doses are converted back to arithmetic doses). Importantly, the ratio cutoff of 5.0 should be determined in arithmetic space. The hypothetical example below shows that a BMD/BMDL ratio in log space that is <5.0 can be equivalent to a ratio of 800 once the doses are converted back into arithmetic space (**Table 1**). A BMD/BMDL ratio of 800 in arithmetic space would not indicate confidence in the modeling.

Table 1. Hypothetical Example Demonstrates That BMD/BMDL Ratios Differ in Log and Arithmetic Space

	BMD	BMDL	Ratio	Notes
log	8.1	1.63	4.97	(still<5.0)
arithmetic	3293	4.1	803	

Dr. David Gaylor was asked to independently review the Gradient (2014) report and confirmed the conclusions reached by ToxStrategies regarding the mistake made by Gradient and implications in terms of identifying acceptable models (See **Attachment D**)

8.0 The BMD/BMDL Ratio in Arithmetic Space Supports Linear Model

Given the above, the BMD/BMDL ratios in Tables 3.1 to 3.12 in the Gradient report are not informative for decision-making regarding the acceptability of the various models. Instead, the BMD and BMDL ratios for each modeling scenario should be converted from log space to arithmetic space before computing a BMD/BMDL ratio. **Table 2** below shows the BMD/BMDL ratios in arithmetic space for WBC and lymphocyte counts using both concurrent and historical control data. Among the individual models yielding acceptable fits, the linear model is the only model with a ratio <5.0 in all cases. Among the exponential models, the BMD/BMDL ratio for the M4 model ranges from 6.94 to >10. Given that the BMD and BMDL differ by up to an order of magnitude, the M4 model should be removed from further consideration. The ratio for M2 is <5.0 only for WBC with concurrent control data; however, the AIC for the M2 model is greater than the AIC for the linear model and, as such, the linear model would be selected over M2 according to the criteria used by Gradient. Additionally, the linear model is the more parsimonious of the two models (i.e., linear vs. M2). In short, based on the analyses in **Table 2**

(and criteria outlined by Gradient, see **Section 7** above), only the linear models are sufficient for POD selection. This is true for both WBC and lymphocytes— regardless of whether one uses concurrent or historical control data.

Table 2. BMD/BMDL Ratios in Arithmetic Space*

Endpoint	**Dose**	**Control**	**Model**	**AIC**	**BMD**	**BMDL**	**Ratio**
WBC count	Ln(dose+1)	Concurrent	Linear	109.06	51.23	12.66	4.05
			Exp M4	109.17	32.96	4.75	6.94
			Exp M2	109.17	32.96	6.99	4.72
Endpoint	**Dose**	**Control**	**Model**	**AIC**	**BMD**	**BMDL**	**Ratio**
WBC count	Ln(dose+1)	Historical	Linear	111.579	73.13	16.12	4.54
			Exp M4	111.582	48.88	5.54	8.82
			Exp M2	111.582	48.88	8.78	5.57
Endpoint	**Dose**	**Control**	**Model**	**AIC**	**BMD**	**BMDL**	**Ratio**
Lymphocyte count	Ln(dose+1)	Concurrent	Linear	101.65	65.48	14.45	4.53
			Exp M4	101.55	39.47	4.12	9.58
			Exp M2	101.55	39.47	7.26	5.44
Endpoint	**Dose**	**Control**	**Model**	**AIC**	**BMD**	**BMDL**	**Ratio**
Lymphocyte count	Ln(dose+1)	Historical	Linear	102.60	75.51	15.89	4.75
			Exp M4	102.46	46.43	4.38	10.60
			Exp M2	102.46	46.43	7.96	5.83

*Adapted from Gradient Tables 3.2, 3.4, 3.6, 3.8, and 3.13

Another line of evidence supporting selection of linear models for sulfolane is the scaled residuals. Scaled residuals provide a measure of the difference between observed responses in a dataset and the predicted responses in a mathematical model. The scaled residual of most interest for BMD modeling is the residual of the predicted and observed response nearest the predicted BMD. As was shown in the Gradient report, the scaled residual values for the linear models were slightly better (i.e., lower in absolute value) than for the exponential model in all cases. This indicates that the linear models were better at predicting response near the benchmark response (i.e., 1 SD from control mean).

9.0 BMDL Selection

Based on the above considerations, we believe that the most scientifically defensible BMDL is 16 mg/kg/day. This BMDL reflects use of the more robust historical data for blood cell variability in the control group and application of the linear model to datasets for both WBCs and lymphocytes. Since modeling of WBC count and lymphocytes provided nearly identical results, the BMDL of 16 mg/kg/day effectively represents a BMDL value based on WBC count and lymphocytes. This is a scientifically defensible approach given that there is no clear biological rationale for selecting one endpoint (WBC or lymphocytes) over the other, especially since they are essentially measures of the same effect given that lymphocytes account for approximately 80% of WBCs in rats (Faas et al., 2005; Thompson et al., 1986). Relying on both endpoints is essentially akin to developing RfDs based on co-critical studies as the USEPA has proposed in several recent IRIS assessments. For example, in a recent formaldehyde draft assessment, three RfC values derived from three studies measuring related (but not identical) effects (reduction in spirometric parameters, asthma prevalence, and atopy) were considered co-critical (USEPA, 2011). The USEPA then averaged these three values together, "The RfC is taken as the average

of the RfCs from the three cocritical studies (See Section 6.2.1.2)". Notably, because the WBC and lymphocyte BMDL values were ~16 mg/kg/day, these would result in similar 'co-critical' RfD values. Although the WBC and lymphocyte data derive from a single study, averaging the BMDLs (or the RfDs) is, in principal, consistent with *de facto* EPA practices. We use the latter terminology because we are unaware of any specific USEPA guidance on co-critical toxicity values. For example, this terminology is not discussed in USEPA's *A Review of the Reference Dose and Reference Concentration Processes* (USEPA, 2002).

Given the overall similarity in fits of the linear and M2 models, one could consider averaging the BMDL values for the two models together. However, according to USEPA scientists (Davis et al., 2011):

> *"The model with the smallest AIC would be considered the model that most parsimoniously fits the data, and its BMDL would serve as the POD. The current technical guidance to use the smallest AIC, even when the differences are very small…. When multiple models return the* ***exact*** *same AIC, their BMDLs can be averaged to obtain the POD."*[bolding emphasis added]

Overall, applying BMD/BMDL ratio and AIC criteria, the linear models are the most suitable for POD selection. Despite the above recommendation noted by Davis and his EPA coauthors (Davis et al., 2011), some analysts may prefer to average models with very similar AIC values and with BMD/BMDL ratios below or close to 5.0. **Attachment E** contains BMDL values based on averaging linear and M2 models.

10.0 Relevance of Changes in Blood Cell Counts

The HLS (2001) study authors questioned the relevance of the blood cell count findings. Specifically, the original study authors stated:

> *"There was no evidence of any chronic inflammatory change or of comprised immune function in females, or any effect upon bone marrow, thymus or spleen that would account for the reduced numbers of these leucocytes. The toxicological significance of this change is therefore unclear."*

The HLS (2001) study authors further stated that the trend for effects on blood cells "did not follow a strong trend with dosage" (HLS, 2001).

It should be noted that similar effects on blood cell counts *in humans* were also considered of questionable relevance in a USEPA IRIS Assessment for benzene. In the USEPA assessment of benzene (USEPA, 2001), the decrease in lymphocytes in humans were characterized as follow:

> *"…the endpoint is not very serious in and of itself. Decreased ALC [absolute lymphocyte count] is a* ***very sensitive sentinel effect*** *that can be measured in the blood,* ***but it is not a frank effect****, and there is* ***no evidence that it is related to any functional impairment*** *at levels of decrement near the BMR."*

In short, USEPA considered the decrease in lymphocytes in humans exposed to benzene as a "not very serious effect". Unlike benzene, sulfolane is not genotoxic and there is no evidence that it is carcinogenic. The fact that it is questionable as to whether these effects on blood cell counts is even adverse should be taken into consideration in the course of decision making when establishing the RfD. In other words, when relying on expert judgment in the course of selecting BMDL modeling results and uncertainty factors, it is imperative that one not compound conservatism for an effect that may not even be adverse.

11.0 Uncertainty Factors and Total Adjustments Inherent in the Seven Publically Available RfDs

Application of UFs is not prescriptive but rather requires expert judgment. This is underscored by **Table 3** below, which indicates that all seven of the publically available RfD or TDI values based on the HLS (2001) data accounted for uncertainty in a different manner. Some risk assessors split 3- or 10-fold UF values into two different UF categories (e.g., CCME). Notably, the USEPA reduced the default database UF from 10 to 3. Most risk assessors applied a full 10-fold subchronic UF because the HLS (2001) study was a 90-day subchronic study. There was divergence in the extrapolation across species. Several groups applied the default 10-fold interspecies UF, whereas two groups employed a more refined modeling approach by applying allometric scaling. Among the groups that applied allometric scaling, Thompson et al. (2013) also applied a 3-fold interspecies UF to account for potential species differences in pharmacodynamics. While consistent with typical USEPA practices for noncancer endpoints (SEPA, 2011), such an UF is not entirely necessary, as data indicate that allometric scaling generally accounts for cross species differences in toxicity (which is comprised of both pharmacokinetics and pharmacodynamics). In fact, the USEPA only uses allometric scaling (without additional interspecies UFs) when extrapolating cancer endpoints across species. The Texas Commission for Environmental Quality (TCEQ) uses a harmonized approach whereby no additional interspecies UFs are applied to either cancer or noncancer endpoints when allometric scaling is conducted and, as noted above, this was subject to a robust peer-review by an independent panel of experts convened by TERA (TERA, 2011; TCEQ, 2012).

Table 3. Uncertainty Factors and Total Adjustments Inherent in the Seven Publically Available RfDs

Study	BMDL	NOAEL	Adjustment resulting from $BW^{3/4}$ scaling	UF (inter)	UF (intra)	UF (subchron)	UF (DB)	UF (composite)	RfD or TDI	Total Adj*
Thompson et al. (2013)	16	NA	4	3	3	10	3	300	0.01	1200
TCEQ (2011)	16.1	NA	4	1	10	10	3	300	0.013	1200
Magee (2012)	11.64	NA	No	10	10	10	1	1000	0.01	1000
HC (2014)	4.12	NA	No	10	10	10 (partial)	10 (partial)	1000	0.004	1000
USEPA (2012a)	NA	2.9	No	10	10	10	3	3000	0.001	3000
CCME (2006)	NA	2.9	No	10	10	3 (partial)	3 (partial)	300	0.0097	300

*Includes allometric scaling where applicable and UFs

As shown in **Table 3** above, Thompson et al. (2013) applied a 3-fold UF for intraspecies variability. This decision was based on consideration of several factors. First, the effect on blood cells was only observed in female rats. The only adverse effect in male rats was a species and gender-specific effect in the kidney (hydrocarbon nephropathy) that is not relevant to humans. This means that the blood cell count data used for RfD derivation was derived from a potentially sensitive subpopulation (i.e., females). No other toxicity was reported in the HLS (2001) study. Second, the reduction in blood cell counts was considered to be of questionable significance by the HLS study authors (HLS, 2001). Lymphopenia, for example, can occur for a variety of reasons—most typically in response to increased levels of circulating glucocorticoids caused by stress (endogenous glucocorticoid release) or treatment with exogenous glucocorticoids. A mild stress reaction secondary to exposures to sulfolane may explain the lymphopenia. One could even speculate that the taste or smell of sulfolane in drinking water could have been enough to trigger a stress response. Importantly, the changes were relatively small and not accompanied by adverse effects in any lymphoid organs (both spleen weights and histology were unaffected by treatment). Notably, the USEPA has characterized reduction in blood cells in humans exposed to benzene as "not very serious" (USEPA, 2002).

As indicated in the far column in **Table 3** ("Total Adj" column), Thompson et al. (2013) effectively applied a 1200-fold adjustment to the POD (based on allometric scaling and the composite UF applied). Notably, such a 1200-fold adjustment to the POD exceeds the composite UFs applied by all but one of the other groups of risk assessors that have developed PODs for sulfolane, including those that relied on a NOAEL approach. For example, CCME (2006) and ATSDR (2010) applied composite UFs of 300 and 100, respectively (ADEC, 2014). It is clear that the total adjustment (1200-fold) applied in Thompson et al. (2013) is second only to the large 3000-fold adjustment applied by USEPA (2012a) based on their NOAEL approach. Thus, Thompson et al. (2013) applied considerable adjustments in the derivation of the RfD.

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Attachment A

Examples of Some of the Specific Deficiencies in Zhu et al. (1987)

Examples of Some of the Specific Deficiencies in Zhu et al. (1987)

1) *The paper contains very limited information on materials and methods* - It is impossible to assess the validity of many results provided in the paper because information on how the data was obtained is not provided. For example, mean bone marrow cell counts are provided, but no method for this complex analysis with significant opportunity for analytical variability is described. P-values are given, but information on the statistical testing used is not provided. While some clinical laboratory and histopathology results are reported, details about what tissues were collected and evaluated are not provided. There is no description of the method of blood.

2) *It is unclear if the testing was performed under conditions that approximated current GLP guidelines* - No information is provided about the supplier of test animals, their strain and how they were housed and fed. The health status of the animals is not reported. Information on the test article – supplier, grade, purity etc. – is not provided, nor do they identify how the animals were dosed (e.g., gavage, drinking water, feed). Symptoms of toxicity for the acute toxicity test are provided, but the time at which they appeared is not.

3) *A number of clinical laboratory results are cited as being different from controls without any substantiation of biological significance and in some cases, no statistical testing results* - Throughout the descriptions of the 90-day and 6-month toxicity tests, differences for serum enzyme activities and hematology results are cited. However, no data is provided for the 90-day studies, and only a few select results are provided from the 6-month study. This makes it impossible to determine the true biological significance of any of the reported clinical laboratory results.

4) *Specific Issues for the 90-day Oral Toxicity Test Results:*
   a) *The alkaline phosphatase (ALP) activity is reported to have declined in the low- and mid-dose group guinea pigs*. It is not clear from the p-values provided if this is in one sex or if male and female data were combined. Serum ALP decreases in many animals, including guinea pigs, as they mature (White and Lang, 1989). Since we do not have access to the data, it is not possible to evaluate why this change was statistically significant in only two dose groups. It is quite possible that ALP was decreasing in controls and all dose groups at slightly different rates that simply showed up as a statistically significant – but biologically insignificant – change in two groups.

   b) *Total leukocyte count ("white blood cell") declined but it is unclear in which dose groups*. The total leukocyte count was reported to decline in all the dose groups of guinea pigs – but again from the single p-values given for each dose it also appears that male and female were combined. This is not routine practice in the analysis of any safety study data whether it is clinical laboratory data, organ weights, or other results to report male and female data combined. We do not have numerical results or differential leukocyte counts to evaluate the biological significance of a decrease

in mean total leukocyte count, which makes these results unsuitable for any further use.

c) *Histopathology was apparently performed, but no results were given*. Given the results reported from the interim (3 months) histopathology reported in the 6-month study this is very significant lapse in the scientific validity of this publication. Do we assume that nothing was found? This would have significant implications for the interpretation of the results for the spleen and liver histopathology results in the six-month study in guinea pigs.

d) *The authors' conclusions that the tests point to sulfolane "influences" on the blood system, liver and kidney are completely unsubstantiated*. The only potential liver enzyme result cited was a decreased ALP activity in guinea pigs and rats, but the most likely explanation for this is random variation among the groups during a time when ALP activity is declining due to maturation. Urine volume and urine GGT activity were reported as being high in the high-dose rats, but it is unclear how urine was collected for volume calculations and whether drinking water contamination (which is common) might have occurred. Collection of urine for enzymatic analysis has to be done differently than for routine urinalysis and urine GGT activity has to be standardized against either urine volume or creatinine (Ragan et al., 1989). It is not clear if this was done in this study and so the urine volume and GGT results cannot be used to substantiate the presence of renal toxicity. Problems with substantiating the biological significance of the hematology results were discussed above. "Thrombin" is said to have declined, but it is not clear if this means that thrombin protein was quantified (unlikely) or that thrombin time was measured. Thrombin time is a coagulation function test and a decreased time is an indication of enhanced coagulation function and not a deficit.

5) *Specific Issues for the Guinea Pig 6-month Toxicity Test Results:*

a) *At both 3 and 6 months, serum enzymes ALT (formerly called GPT) and/or AST (formerly called GOT) were reported to be low compared to controls*. Group mean results for both enzymes are reported for higher dose groups along with a control mean value. An F-statistic from a statistical test that is not described and p-value are provided to demonstrate statistical significance. Slight differences in mean serum enzyme results that are statistically significant occur routinely in safety assessment studies but are not necessarily biologically significant (Carakostas, 1992). Low serum enzyme results have an equivocal biological meaning. They can sometimes be seen when hepatic metabolic activity is altered, but most times decreases are small and biologically insignificant. However, it is not clear in the Zhu study whether the treatment groups are really low or if the control group results are higher than normal in this study. No laboratory specific reference ranges are provided for guinea pigs and so the only default ranges we can use are from the literature. Reference ranges for guinea pig ALT and AST from the textbook <u>The Clinical Chemistry of Laboratory Animals</u>, edited by Loeb and Quimby (1989), are shown below.

	Males (mean ± 2SD)	Females (mean ± 2SD)
ALT (GPT)	31.1 - 58.1	24.5 - 53.1
AST (GOT)	29.2 - 67.2	31.5 - 59.5

b) There is no interpretation of the serum enzyme results in the Zhu paper, only an indication that they are statistically different from controls. However, compared to the reference ranges, the treatment group guinea pig results are all in approximately the middle of the reference range while the control group results are at or slightly above the upper limit of the range. Biologically, all the reported ALT and AST results in the Zhu study would be considered not significant.

c) There are two additional issues related to the serum enzyme results. First, in the guinea pig neither ALT nor AST are liver specific enzymes (White and Lang, 1989). Therefore, changes in the serum activity of these two enzymes cannot automatically be assumed to indicate a change in liver homeostasis. Second, it appears that Zhu et al. have again combined male and female data for statistical analysis since only one mean value and one F-statistic is given for each enzyme result. This is not standard practice in the evaluation of data from safety assessment studies. Reference ranges for ALT and AST are similar for male and female rats, but are not identical.

d) The meaning of bone marrow cell counts is unclear given the lack of detail about methodology and lack of concurrent peripheral blood total and differential leukocyte counts. There are numerous methodological and hematological issues with the bone marrow cell count data provided:

i) There are no collection methods, processing methods or counting methods cited, and the source of the bone marrow collected was also not provided. Absence of this information does not allow assessment for determining whether methodological errors might have affected results. Bone marrow cell counts are not a typical or standardized toxicity assessment tool and so detailed methods should have been provided.

ii) There is no information given for how skilled or experienced the authors were in conducting this analysis. Marrow cell counting methods cited in the literature involve significant manipulation of cells and are subject to wide degrees of variation in results due to the process of flushing hematopoietic cells from the bone, processing the marrow for counting, calibrating the counting equipment and conducting the counts. No information on quality control or historical cell-count ranges for guinea pig bone marrow cell counts in the author's laboratory was provided.

iii) Only means of the bone marrow cell counts for each dose group were provided. There is no data on the variation present among the treatment groups and no information on control guinea pig marrow cell counts from control groups in

other studies so that the context of the results can be understood. It is entirely possible that individual results from guinea pigs across all the groups over-lap to a very great degree given the closeness in mean results compared to the size of the means.

iv) Clinically, bone marrow findings are not evaluated without concurrent peripheral blood hematology results and none were provided in the paper. Without peripheral blood counts, a reason for a change in marrow cell counts cannot be determined.

v) Bone marrow cell counts from the 3-month interim sacrifice were reported, but bone marrow cell counts were either not performed or results were not reported at the end of the study. It seems very unusual for such a complex evaluation to be performed only at an interim period in a 6-month safety study. This is very unfortunate since time-course data might have allowed some evaluation of biological significance.

vi) The accuracy of the marrow cell counting methodology and the biological meaning and significance of the bone marrow cell count results cannot be determined from the information provided in the paper. Therefore, use of these results to model risk is inappropriate. The accuracy and biological relevance of any model based on these results is equally unknown.

e) *The incidence results of microscopic lesions in the spleen and liver may be valid but must be interpreted in light of the overall problems with the lack of information about the conduct of this study*. An apparent increasing incidence of lesions in the spleen (translation likely means a reduced number of lymphocytes in the white pulp) and fatty change in the liver in a dose-related pattern was reported. However, the incidence at lower dose levels was one or two animals from the entire group. It is not clear how often these changes have been reported from control groups in this laboratory in the past (historical incidence). It is also not clear if the low incidences observed in the 2.5 and 25 mg/kg groups were confirmed via a "blinded" evaluation of the spleen and liver slides or if they were confirmed via a peer review. Given the importance of the microscopic pathology information in the outcome of modeling and regulatory reviews for sulfolane, it seems prudent to ensure that these results are accurate. Andersen et al. (1977) reported fatty degeneration in guinea pigs exposed by inhalation to sulfolane at 200 mg/m^3 5 days per week for 13 weeks, but not at several exposure concentrations at 159 mg/m^3 and lower. A 159 mg/m^3 exposure via inhalation is roughly equivalent to a dose of 192 mg/kg/day in a rat. A similar conversion for guinea pigs result in a somewhat lower dose, but nonetheless quite a bit higher than the 0.25 mg/kg/day NOAEL reported by Zhu et al. in guinea pigs dosed orally. This suggests that the small incidence rates of fatty change at the 2.5 and 25 mg/kg/day doses in the Zhu guinea pig study should be viewed with some degree of skepticism, or at least caution, about their biological significance given the issues raised about this study.

Attachment B

Examples of Limitations of the NOAEL/LOAEL Approach

Examples of Limitations of the NOAEL/LOAEL Approach

The LOAEL/NOAEL approach has several limitations including: (a) the LOAEL/NOAEL values are limited to the doses tested; (b) the LOAEL/NOAEL does not appropriately reflect study size; (c) the LOAEL/NOAEL cannot be directly compared across studies and endpoints based on a common response level (e.g., 10% increased risk; and (d) the approach can inappropriately reward poorer studies with less statistical power to detect effects (ToxStrategies, 2010; Thompson et al., (2013). In contrast, BMD modeling is the preferred method for dose–response modeling because it takes into account the shape of the dose–response curve, the confidence limits reflect the size of the study and it allows comparison of comparable results across studies and endpoints at any response level (e.g., 10% increased risk) (Crump, 1984; Leisenring and Ryan, 1992; Allen et al., 1998; Gaylor et al., 1998; USEPA, 2000; Davis et al., 2011).

Attachment C

Historical Control Hematology Data for the Huntingdon Life Sciences (HLS) Laboratory[1]

[1] Note – data provided in **Attachment C** is that for the applicable strain of rats used in the HLS study (i.e., "Crl:CD (SD)IGS BR", which is the same as "IGS CD" noted in historical control database report) and applicable HLS laboratory where both the in-life portion of the study and all hematology analyses were conducted ("Eye"; abbreviated "ERC"); additionally, animals in sulfolane were received at 4 weeks of age + 2 weeks acclimation + 13 weeks on test = 19 weeks at termination. In summary, applicable historical control data is that for female IGS CD rats, 16-21 weeks of age, from the ERC facility.

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BACKGROUND DATA BULLETIN

Volume 14 Number 1

November 2003

This issue contains the following:

Eye and Huntingdon
Research Centres

Rats:
IGS CD and Han Wistar

Biochemistry, Haematology
and Urinalysis

The objective of this publication is to provide Study Directors with up to date information on Huntingdon Life Sciences normal ranges for commonly measured parameters. The publication is confidential to Huntingdon Life Sciences and only sections directly relevant to the interpretation of specific studies should be disclosed to clients.

Prepared by the
Statistics Department

CONTENTS

Table 2.2 (cont.)

Rats (IGS CD) - ERC

Haematology

Parameter	sex	age	n	1%	5%	50%	95%	99%	mean	s.d.
MCV	M	8.4- 12.3	578	51.7	54.1	58.0	62.3	65.1	58.08	2.580
		12.4- 16.3	156	49.4	51.2	55.2	60.2	62.1	55.35	2.613
		16.4- 21.3	387	48.7	50.1	53.4	56.4	57.7	53.35	1.953
		29.4- 34.3	194	47.9	49.0	52.4	56.4	57.8	52.44	2.183
		42.4- 47.3	9	50.0	50.0	51.6	55.9	55.9	52.60	1.936
		54.4- 61.3	60	47.6	48.0	52.3	55.6	57.2	52.35	2.110
		80.4- 87.3	60	46.8	48.9	53.4	57.5	58.3	52.98	2.438
		105.4-113.3	39	50.1	50.5	54.8	58.2	64.0	54.98	2.554
	F	8.4- 12.3	581	52.3	53.7	56.9	60.2	61.9	56.86	1.946
		12.4- 16.3	142	50.1	52.4	55.8	59.7	60.7	55.77	2.049
		16.4- 21.3	393	50.6	51.8	54.6	58.2	60.4	54.84	1.958
		29.4- 34.3	190	51.5	52.2	54.9	58.6	61.4	55.05	1.923
		42.4- 47.3	6	54.8	54.8	56.4	57.1	57.1	56.28	0.784
		54.4- 61.3	53	53.0	53.4	55.2	59.7	60.5	55.69	1.874
		80.4- 87.3	58	50.1	51.0	56.5	60.3	63.3	56.30	2.334
		105.4-113.3	19	54.7	54.7	57.6	67.2	67.2	58.14	2.939
WBC	M	8.4- 12.3	582	6.26	8.11	12.44	18.76	22.20	12.734	3.2625
		12.4- 16.3	166	5.87	7.14	13.01	22.09	35.21	13.649	4.6502
		16.4- 21.3	387	7.41	8.42	12.17	17.68	21.01	12.528	2.8551
		29.4- 34.3	194	6.93	8.03	11.02	15.15	21.20	11.180	2.3571
		42.4- 47.3	9	7.02	7.02	11.24	12.49	12.49	9.892	2.1064
		54.4- 61.3	60	6.30	6.70	9.70	13.88	21.56	9.859	2.4785
		80.4- 87.3	120	5.01	6.51	9.86	15.18	24.12	10.255	2.8647
		105.4-113.3	77	5.88	6.30	9.42	17.18	28.01	10.294	3.5808
	F	8.4- 12.3	586	5.40	6.20	10.21	15.42	18.80	10.450	2.7967
		12.4- 16.3	142	4.00	5.65	11.26	19.75	25.08	11.433	4.1049
		16.4- 21.3	393	4.16	5.13	8.56	13.54	16.27	8.872	2.6261
		29.4- 34.3	190	4.14	5.04	7.58	12.31	13.32	7.890	2.0984
		42.4- 47.3	6	4.56	4.56	5.28	7.21	7.21	5.528	1.0475
		54.4- 61.3	52	4.70	4.73	6.80	9.21	9.76	6.909	1.3285
		80.4- 87.3	106	3.10	3.71	6.14	10.99	15.42	6.507	2.1414
		105.4-113.3	44	3.51	3.75	6.76	12.77	13.45	7.208	2.2456
Neutrophils	M	8.4- 12.3	582	0.60	0.80	1.58	3.17	7.35	1.774	1.1445
		12.4- 16.3	166	0.67	0.87	1.62	7.63	18.43	2.454	2.7792
		16.4- 21.3	387	0.58	0.81	1.46	3.17	4.88	1.625	0.8798
		29.4- 34.3	194	0.68	0.95	1.50	2.86	3.90	1.608	0.5981
		42.4- 47.3	9	1.49	1.49	1.77	3.12	3.12	1.964	0.4828
		54.4- 61.3	60	0.71	0.90	1.50	2.85	3.13	1.621	0.5390
		80.4- 87.3	120	0.82	0.97	1.95	5.32	10.58	2.328	1.5254
		105.4-113.3	77	0.91	1.24	2.31	7.16	15.02	3.035	2.2019
	F	8.4- 12.3	586	0.36	0.56	1.00	2.27	4.41	1.169	0.8118
		12.4- 16.3	142	0.40	0.54	1.18	6.78	11.98	1.821	2.0816
		16.4- 21.3	393	0.34	0.47	0.83	1.96	3.05	0.972	0.4912
		29.4- 34.3	190	0.39	0.46	0.89	2.07	2.95	1.007	0.5449
		42.4- 47.3	6	0.67	0.67	0.99	1.17	1.17	0.977	0.1841
		54.4- 61.3	52	0.42	0.63	1.17	1.86	2.32	1.203	0.3538
		80.4- 87.3	106	0.55	0.73	1.56	3.88	5.68	1.772	0.9426
		105.4-113.3	44	0.96	1.05	2.05	6.34	6.61	2.558	1.3695

Table 2.2 (cont.)

Rats (IGS CD) - ERC

Haematology

Parameter	sex	age	n	1%	5%	50%	95%	99%	mean	s.d.
Lymphocytes	M	8.4- 12.3	582	5.13	6.32	9.99	15.19	18.19	10.234	2.6705
		12.4- 16.3	166	4.86	5.43	10.09	16.08	20.11	10.344	3.0690
		16.4- 21.3	387	5.73	6.62	9.90	14.52	16.17	10.091	2.3716
		29.4- 34.3	194	4.98	6.08	8.62	12.29	18.00	8.729	2.0598
		42.4- 47.3	9	4.92	4.92	7.73	8.64	8.64	6.940	1.6021
		54.4- 61.3	60	4.50	4.97	7.03	10.28	16.79	7.370	1.9664
		80.4- 87.3	120	3.51	4.56	6.81	10.39	12.15	6.987	1.6817
		105.4-113.3	77	3.42	3.72	6.09	9.46	10.93	6.229	1.6384
	F	8.4- 12.3	586	4.39	5.19	8.52	13.06	14.70	8.712	2.3379
		12.4- 16.3	142	2.99	4.64	8.68	13.50	18.65	8.900	2.8937
		16.4- 21.3	393	3.43	4.14	7.19	11.22	14.45	7.368	2.2895
		29.4- 34.3	190	3.19	3.85	6.10	10.05	11.82	6.314	1.8193
		42.4- 47.3	6	3.07	3.07	3.95	5.86	5.86	4.082	1.0108
		54.4- 61.3	52	3.10	3.33	4.94	6.74	6.82	5.028	1.0081
		80.4- 87.3	106	1.95	2.24	3.90	6.69	9.90	4.126	1.3321
		105.4-113.3	44	1.57	1.98	3.69	6.31	7.21	3.914	1.1612
Eosinophils	M	8.4- 12.3	582	0.03	0.05	0.11	0.25	0.35	0.126	0.0630
		12.4- 16.3	166	0.03	0.06	0.16	0.35	0.64	0.180	0.0987
		16.4- 21.3	387	0.05	0.09	0.17	0.30	0.42	0.178	0.0742
		29.4- 34.3	194	0.08	0.11	0.20	0.34	0.53	0.211	0.0819
		42.4- 47.3	9	0.16	0.16	0.26	0.37	0.37	0.252	0.0657
		54.4- 61.3	60	0.08	0.10	0.19	0.31	0.45	0.188	0.0688
		80.4- 87.3	120	0.05	0.07	0.17	0.32	0.81	0.183	0.0980
		105.4-113.3	77	0.02	0.06	0.15	0.43	0.51	0.165	0.0950
	F	8.4- 12.3	586	0.05	0.06	0.12	0.28	0.38	0.141	0.0678
		12.4- 16.3	142	0.04	0.06	0.17	0.38	0.62	0.184	0.0984
		16.4- 21.3	393	0.05	0.07	0.13	0.26	0.38	0.145	0.0637
		29.4- 34.3	190	0.04	0.07	0.13	0.29	0.35	0.147	0.0655
		42.4- 47.3	6	0.10	0.10	0.13	0.17	0.17	0.130	0.0253
		54.4- 61.3	52	0.05	0.08	0.12	0.21	0.25	0.136	0.0495
		80.4- 87.3	106	0.05	0.06	0.11	0.28	0.42	0.132	0.0646
		105.4-113.3	44	0.02	0.02	0.10	0.26	2.31	0.159	0.3353
Basophils	M	8.4- 12.3	582	0.00	0.00	0.03	0.08	0.10	0.036	0.0229
		12.4- 16.3	166	0.00	0.00	0.03	0.09	0.11	0.039	0.0241
		16.4- 21.3	387	0.00	0.01	0.03	0.09	0.10	0.035	0.0228
		29.4- 34.3	194	0.00	0.00	0.02	0.05	0.10	0.027	0.0178
		42.4- 47.3	9	0.01	0.01	0.03	0.04	0.04	0.027	0.0100
		54.4- 61.3	60	0.00	0.00	0.01	0.10	0.10	0.020	0.0238
		80.4- 87.3	120	0.01	0.01	0.02	0.05	0.10	0.025	0.0151
		105.4-113.3	77	0.00	0.01	0.02	0.05	0.12	0.026	0.0169
	F	8.4- 12.3	586	0.00	0.00	0.02	0.06	0.08	0.026	0.0171
		12.4- 16.3	142	0.00	0.00	0.03	0.07	0.11	0.029	0.0203
		16.4- 21.3	393	0.00	0.00	0.02	0.04	0.06	0.018	0.0139
		29.4- 34.3	190	0.00	0.00	0.01	0.04	0.06	0.015	0.0135
		42.4- 47.3	6	0.00	0.00	0.01	0.02	0.02	0.010	0.0089
		54.4- 61.3	52	0.00	0.00	0.01	0.02	0.03	0.008	0.0083
		80.4- 87.3	106	0.00	0.00	0.01	0.03	0.06	0.012	0.0091
		105.4-113.3	44	0.00	0.00	0.01	0.03	0.03	0.013	0.0076

Attachment D

Comments Offered by Dr. David Gaylor on the Gradient (2014) Report

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Prepared by: David W. Gaylor, Ph.D.

Comments on Gradient Report, "Review and Verification of Existing Sulfolane Dose-Response Assessments", dated August 15, 2014.

General Comments

As listed in Table 3.13 in the Gradient Report, the Linear, Power, and Polynomial models generally reverted to the linear form. Hence, this family of models only provided one unique dose-response model.

The Gradient Report provides a comprehensive review of published animal studies that investigate biological effects in animals exposed orally to sulfolane.

Specific Comments

Table 2.2 in the Gradient Report lists the dose-response data used to calculate benchmark doses (BMD's) for various biological effects observed in animals exposed orally to sulfolane. Table 3.13 provides a summary of BMD's calculated.

Gradient implies on page 12 of their Report that U.S. EPA's approach was followed in using the results listed in Table 13.3 to calculate a Point of Departure (PoD). EPA's in its BMDS Wizard indicates that BMD/BMDL ratios exceeding a factor of 5 indicate imprecise estimates of effects and should not be used for determining the PoD. However, Gradient did not follow the EPA's BMDS Wizard approach and used all of the results in Table 3.13 to set a PoD including several results where the BMD/BMDL ratio exceeded 5, e.g., for white blood count with concurrent controls for exponential model 4, BMD/BMDL = 32.96 / 4.75 = 6.94.

Hence, applying the EPA approach for using only results where the BMD/BMDL ratio is less than 5 restricts the results for the white blood count with concurrent controls to the linear model with a BMDL = 12.66 mg/kg-day and the exponential model 2 with a BMDL = 6.99 mg/kg-day. According to the EPA's approach, since these two BMDLs are within a factor of 3 they are considered sufficiently close and the model with the best goodness-of-fit, lowest Akaike Information Criteria (AIC), is selected (in this case the linear model with the BMDL = 12.66). Recall that this model is linear for the transformed dose, ln(dose +1).

For the white blood count with historical controls only the linear model satisfies the criterion of the BMD/BMDL less than 5, giving a BMDL = 16.12 mg/kg-day.

For lymphocytes with concurrent controls only the linear model satisfies the criterion of the BMD/BMDL less than 5, giving a BMDL = 14.45 mg/kg-day.

For lymphocytes with historical controls only the linear model satisfies the criterion of the BMD/BMDL less than 5, giving a BMDL = 15.89 mg/kg-day.

Since these four BMDL's listed above are within a factor of 3, they are not considered divergent (see Section 4, page 12 of the Gradient Report). According to the U.S. EPA BMD Analysis Framework, Figure 3.1, the BMDL selected for the PoD is based on the qualifying model with the lowest AIC. For the four qualifying BMDL estimates listed above, the linear model with concurrent controls for lymphocytes with a BMDL=14.45 mg/kg-day has the lowest AIC (see Table 3.13). Hence, the **recommended PoD= 14.45 mg/kg-day,** as opposed to the PoD = 6mg/kg-day suggested in the Gradient Report which failed to disregard imprecise results where the BMD/BMDL exceeded a factor of 5.

Attachment E

BMDL and Associated RfD Values Based on the Average of Linear and M2 Models

Table E.1: BMDLs Based on Average of Linear & M2 Models

Endpoint	Dose	Control	Model	AIC	BMD	BMDL	Ratio
WBC count	Ln(dose+1)	Concurrent	Linear	109.06	51.23	12.66	4.05
			Exp M4	109.17	32.96	4.75	6.94
			Exp M2	109.17	32.96	6.99	4.72
			Average:Linear&M2	--	--	9.8	NA
Endpoint	**Dose**	**Control**	**Model**	**AIC**	**BMD**	**BMDL**	**Ratio**
WBC count	Ln(dose+1)	Historical	Linear	111.579	73.13	16.12	4.54
			Exp M4	111.582	48.88	5.54	8.82
			Exp M2	111.582	48.88	8.78	5.57
			Average:Linear&M2	--	--	12.5	NA
Endpoint	**Dose**	**Control**	**Model**	**AIC**	**BMD**	**BMDL**	**Ratio**
Lymphocyte count	Ln(dose+1)	Concurrent	Linear	101.65	65.48	14.45	4.53
			Exp M4	101.55	39.47	4.12	9.58
			Exp M2	101.55	39.47	7.26	5.44
			Average:Linear&M2	--	--	10.9	NA
Endpoint	**Dose**	**Control**	**Model**	**AIC**	**BMD**	**BMDL**	**Ratio**
Lymphocyte count	Ln(dose+1)	Historical	Linear	102.60	75.51	15.89	4.75
			Exp M4	102.46	46.43	4.38	10.60
			Exp M2	102.46	46.43	7.96	5.83
			Average:Linear&M2	--	--	11.9	NA

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Comments on Gradient Report, "Review and Verification of Existing Sulfolane Dose-Response Assessments", dated August 15, 2014.

General Comments

As listed in Table 3.13 in the Gradient Report, the Linear, Power, and Polynomial models generally reverted to the linear form. Hence, this family of models only provided one unique dose-response model.

The Gradient Report provides a comprehensive review of published animal studies that investigate biological effects in animals exposed orally to sulfolane.

Specific Comments

Table 2.2 in the Gradient Report lists the dose-response data used to calculate benchmark doses (BMD's) for various biological effects observed in animals exposed orally to sulfolane. Table 3.13 provides a summary of BMD's calculated.

Gradient implies on page 12 of their Report that U.S. EPA's approach was followed in using the results listed in Table 13.3 to calculate a Point of Departure (PoD). EPA's in its BMDS Wizard indicates that BMD/BMDL ratios exceeding a factor of 5 indicate imprecise estimates of effects and should not be used for determining the PoD. However, Gradient did not follow the EPA's BMDS Wizard approach and used all of the results in Table 3.13 to set a PoD including several results where the BMD/BMDL ratio exceeded 5, e.g., for white blood count with concurrent controls for exponential model 4, BMD/BMDL = 32.96 / 4.75 = 6.94.

Hence, applying the EPA approach for using only results where the BMD/BMDL ratio is less than 5 restricts the results for the white blood count with concurrent controls to the linear model with a BMDL = 12.66 mg/kg-day and the exponential model 2 with a BMDL = 6.99 mg/kg-day. According to the EPA's approach, since these two BMDLs are within a factor of 3 they are considered sufficiently close and the model with the best goodness-of-fit, lowest Akaike Information Criteria (AIC), is selected (in this case the linear model with the BMDL = 12.66). Recall that this model is linear for the transformed dose, ln(dose +1).

For the white blood count with historical controls only the linear model satisfies the criterion of the BMD/BMDL less than 5, giving a BMDL = 16.12 mg/kg-day.

For lymphocytes with concurrent controls only the linear model satisfies the criterion of the BMD/BMDL less than 5, giving a BMDL = 14.45 mg/kg-day.

For lymphocytes with historical controls only the linear model satisfies the criterion of the BMD/BMDL less than 5, giving a BMDL = 15.89 mg/kg-day.

Since these four BMDL's listed above are within a factor of 3, they are not considered divergent (see Section 4, page 12 of the Gradient Report). According to the U.S. EPA BMD Analysis Framework, Figure 3.1, the BMDL selected for the PoD is based on the qualifying model with the lowest AIC. For the four qualifying BMDL estimates listed above, the linear model with concurrent controls for lymphocytes with a BMDL=14.45 mg/kg-day has the lowest AIC (see Table 3.13). Hence, the **recommended PoD= 14.45 mg/kg-day,** as opposed to the PoD = 6mg/kg-day suggested in the Gradient Report which failed to disregard imprecise results where the BMD/BMDL exceeded a factor of 5.

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Flint Hills Resources Alaska, LLC

Revised Draft Final
Human Health Risk Assessment

Flint Hills North Pole Refinery
North Pole, Alaska

May 2012

ARCADIS

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Revised Draft Final Human Health Risk Assessment

Flint Hills North Pole Refinery
North Pole, Alaska

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Tables

Figures

Appendices

ABS_d	dermal absorption factor
ABSGI	percent oral absorption efficiency
ACL	alternative cleanup level
ADD	average daily dose
Addendum	Draft Site Characterization Work Plan Addendum
ADEC	Alaska Department of Environmental Conservation
ADHSS	Alaska Department of Health and Social Services
AEC	average exposure concentration
AF	soil-to-skin adherence factor
ALM	Adult Lead Model
ARCADIS	ARCADIS U.S., Inc.
AST	aboveground storage tank
AT	averaging time
ATSDR	Agency for Toxic Substances and Disease Registry
B	permeability ratio
Barr	Barr Engineering Company
BCF	bioconcentration factor
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene and total xylenes
BW	body weight
CalEPA	California Environmental Protection Agency
CDC	Centers for Disease Control and Prevention
CF	conversion factor
city	North Pole, Alaska
cm^2	square centimeter
COI	constituent of interest

COPC	constituent of potential concern
CSF	cancer slope factor
CSFi	cancer slope factor for the ***i*** th constituent
CSM	conceptual site model
DA_{event}	dose per event
Dose	average daily dose or lifetime average daily dose
DRO	diesel range organic
ED	exposure duration
EF	exposure frequency
EFH	Exposure Factors Handbook
ELCR	excess lifetime cancer risk
EPC	exposure point concentration
EPC_a	exposure point concentration in outdoor or indoor air
EPC_{gw}	exposure point concentration in groundwater
EPC_p	exposure point concentration in produce
EPC_s	exposure point concentration in soil
EPC_w	exposure point concentration in groundwater or surface water
ET	exposure time
EU	exposure unit
EU-1	Exposure Unit 1
EU-2	Exposure Unit 2
EU-3	Exposure Unit 3
EV_s	event frequency (soil)
EV_w	event frequency (groundwater or surface water)
FA	fraction absorbed
FC	fraction in contact with soil

FHRA	Flint Hills Resources Alaska, LLC
FI	fraction ingested
GAC	granular activated carbon
GRO	gasoline range organic
HEAST	Health Effects Assessment Summary Tables
HHRA	human health risk assessment
HI	hazard index
HQ	hazard quotient
IR_s	ingestion rate (soil)
IR_w	ingestion rate (groundwater or surface water)
IRIS	Integrated Risk Information System
IRP_{fr}	fruit ingestion rate
IRP_{vg}	vegetable ingestion rate
ITRC	Interstate Technology Regulatory Council
IUR	inhalation unit risk
J&E	Johnson and Ettinger
kg	kilogram
kg/mg	kilograms per milligram
K_p	permeability coefficient
L/day	liters per day
LADD	lifetime average daily dose
$LADD_i$	lifetime average daily dose for the ***i*** th constituent
LAEC	lifetime average exposure concentration
LNAPL	light nonaqueous phase liquid
LOQ	limit of quantitation
m^3/kg	cubic meter per kilogram

mg/cm^2	milligrams per square centimeter
mg/day	milligrams per day
mg/kg	milligrams per kilogram
mg/kg-day	milligrams per kilogram per day
mg/L	milligrams per liter
mg/m^3	milligrams per cubic meter
MRL	minimal risk level
NOAEL	no adverse effect level
OEHHA	California Office of Health Hazard Environmental Assessment
offsite	area located off the property in the downgradient north-northwest direction
onsite	area that is located within the property boundary of the Flint Hills North Pole Refinery
PAH	polynuclear aromatic hydrocarbons
PbB	blood lead concentration
PEF	particulate emission factor
power plant	electrical generating facility
PPRTV	provisional peer reviewed toxicity value
PQL	practical quantitation limit
RAF	relative absorption factor
RAGS	Risk Assessment Guidance for Superfund
RAWP	Work Plan to Conduct a Human Health Risk Assessment
Revised Draft Final HHRA	Revised Draft Final Human Health Risk Assessment
RfD	reference dose
RME	reasonable maximum exposure
RRO	residual range organic
RSL	regional screening level
site	Flint Hills Refinery, North Pole, Alaska

SSA	skin surface area
SSA_s	skin surface area available for contact
SSA_w	skin surface area available for contact with water
sulfolane	tetrahydrothiophene-1,1-dioxide
SVOC	semivolatile organic compound
SWI	Shannon and Wilson, Inc.
t	time
t_{event}	event duration
T_{event}	lag time per event (hours/event)
TEF	toxicity equivalence factor
UCL	upper confidence limit
USEPA	United States Environmental Protection Agency
VF	volatilization factor
VF_{gw}	volatilization factor (groundwater)
VF_{soil}	volatilization factor (soil)
VOC	volatile organic compound
WWTP	wastewater treatment plant
$\mu g/cm^3$	micrograms per cubic centimeter
µg/dL	micrograms per deciliter
µg/L	micrograms per liter
$\mu g/m^3$	micrograms per cubic meter
°C	degrees Celsius
>	greater than

1. Introduction

On behalf of Flint Hills Resources Alaska, LLC (FHRA), ARCADIS U.S., Inc. (ARCADIS) prepared this Revised Draft Final Human Health Risk Assessment (Revised Draft Final HHRA) for the Flint Hills North Pole Refinery located in North Pole, Alaska (site). This HHRA follows the approaches described in the Second Revision Work Plan to Conduct a Human Health Risk Assessment at the Flint Hills North Pole Refinery (RAWP; ARCADIS 2011a). As described in the RAWP (ARCADIS 2011a), FHRA proposed submittal of a RAWP for the site in a project schedule submitted to the Alaska Department of Environmental Conservation (ADEC) on August 2, 2011. FHRA purchased the site from Williams Alaska Petroleum, Inc. in 2004. The HHRA was conducted to answer the question: "Could concentrations of site-related constituents in soil and groundwater pose adverse health effects to current and future site users and potential receptors located offsite, downgradient of the site?" An HHRA uses a conservative (health-protective) approach to answer that question.

No HHRAs or ecological risk assessments have been previously conducted at the site. ARCADIS submitted an ecological conceptual site model (CSM) to the ADEC on June 10, 2011. The purpose of the ecological CSM was to establish whether environmental constituents related to site operations that are present at the site, or that have migrated offsite, will come in contact with ecological receptors. The CSM stated that tetrahydrothiophene-1,1-dioxide (sulfolane) is degraded in surface water in the presence of nutrients and oxygen and does not biomagnify in aquatic food chains. Furthermore, the CSM did not identify any complete exposure pathways for ecological receptors and concluded that no further evaluation is warranted. Therefore, evaluation of potential ecological receptors at the site is beyond the scope of this Revised Draft Final HHRA.

Pore-water samples were collected during the 2012 field season following the approach described in the Draft Site Characterization Work Plan Addendum (Addendum; ARCADIS 2011b) to address a risk assessment data gap identified by the ADEC. The methods for installation of some of the pore-water piezometers needed to be revised because the surface-water body was frozen and true pore-water samples could not be collected. The frozen surface-water body suggests that groundwater/surface water interaction was limited. Therefore, the piezometer samples were likely more representative of groundwater. Because sulfolane degrades more rapidly in the presence of nutrients and oxygen that would be present in the surface water (Alaska Department of Health and Social Services [ADHSS] 2010), and given the limited groundwater-surface water interchange adjacent to a frozen surface-water body, the groundwater collected adjacent to two of the three surface-water bodies in 2012 likely overestimates the surface water concentrations at those locations. The results from the pore-water evaluation do not change the conclusions from the ecological CSM.

This Revised Draft Final HHRA follows protocols presented in the Risk Assessment Procedures Manual (ADEC 2000) that are adopted into regulation in 18 Alaska Administrative Code (AAC) 75. The primary

ADEC references for this Revised Draft Final HHRA include the Draft Risk Assessment Procedures Manual (ADEC 2010a and ADEC 2011c), Cleanup Levels Guidance (ADEC 2008a), Cumulative Risk Guidance (ADEC 2008b) and 18 AAC 75 Oil and Other Hazardous Substances Pollution Control Guidance (ADEC 2008c). Other references used include Risk Assessment Guidance for Superfund (RAGS) (United States Environmental Protection Agency [USEPA] 1989, 1991, 2001, 2004a and 2009a), Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (USEPA 2002a), Vapor Intrusion Pathway: A Practical Guide (Interstate Technology Regulatory Council [ITRC] 2007a), and Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios (ITRC 2007b).

This Revised Draft Final HHRA follows the methodologies, approaches and assumptions of the RAWP (ARCADIS 2011a) and the ADEC approval of the RAWP (ADEC 2011d) to assess risks and hazards to receptors that are potentially exposed to constituents detected in environmental media at the site. In addition, this Revised Draft Final HHRA was developed based on information discussed during a comment resolution meeting held on January 20, 2012 and attended by the ADEC, Oasis/SPB Consulting, FHRA and ARCADIS regarding the Draft HHRA (ARCADIS 2011d) and subsequent follow-up conversations held on January 18 (Technical Project Team meeting), March 9, March 16, May 8, May 10, and May 16, 2012.

For this Revised Draft Final HHRA, potential exposures to constituents detected in two distinct geographical areas were evaluated, both on and offsite. The onsite evaluation identified potential exposures to petroleum hydrocarbon constituents and other constituents associated with refinery operations, including metals and tetrahydrothiophene-1,1-dioxide (sulfolane). The offsite evaluation was conducted for the area north-northwest and downgradient of the site, where only dissolved sulfolane in groundwater is currently identified as a constituent of potential concern (COPC).

It is acknowledged that in 18 AAC 75.990(115), the ADEC defines the term “site” as an “area that is contaminated, including areas contaminated by the migration of hazardous substances from a source area, regardless of property ownership.” For this Revised Draft Final HHRA, the term “onsite” is the area that is located within the property boundary of the Flint Hills North Pole Refinery, and the term “offsite” is the area located off the property in the downgradient north-northwest direction and is based on the approximate extent of the dissolved-phase sulfolane plume detected at concentrations above laboratory reporting limits (approximately 10 micrograms per liter [µg/L]). Figure 2-1 shows the extent of the onsite area and the approximate extent of the offsite area.

This Revised Draft Final HHRA also presents potential site-specific alternative cleanup levels (ACLs) for COPCs that contribute to the majority of the risk or hazard (also referred to as risk/hazard driving COPCs), as appropriate, including benzene, naphthalene, 1,3,5-trimethylbenzene and xylenes in onsite groundwater. A representative range of potential ACLs for the primary risk/hazard driving COPC, sulfolane, was developed based on a range of toxicity criteria and exposure assumptions. ACLs will likely be used to support a feasibility study evaluation of remediation alternatives for the site.

Both current and historical data were evaluated for applicability and usability in the HHRA. Risk assessment data gaps were identified during preparation of the Site Characterization and First Quarter 2011 Groundwater Monitoring Report (Barr Engineering Company [Barr] 2011). These data gaps were filled during the 2011 and 2012 field seasons following the approaches described in the Addendum (ARCADIS 2011b). The data collected during the 2011 and 2012 field seasons were assessed for inclusion into this Revised Draft Final HHRA. Shannon and Wilson, Inc. (SWI) completed the primary historical data collection events in 2000, 2002, 2009 and 2010 (SWI 2002 and 2010).

Estimated hazards and risks are presented based on two primary scenarios:

1. "Provisional peer reviewed toxicity value (PPRTV) Scenario," using toxicity criteria for sulfolane based on the January 2012 USEPA report, along with exposure assumptions approved by ADEC (Section 3).

2. "ARCADIS Comparative Scenario," using the toxicity criteria for sulfolane selected by ARCADIS after its literature review and data evaluations, with the ADEC-approved exposure assumptions (Section 4). In the Uncertainty Assessment of Section 4, also presented is an evaluation of risk using the ARCADIS toxicity criteria for sulfolane, with the exposure assumptions selected by ARCADIS based on its literature review and data evaluations (the "ARCADIS Scenario").

Except as explained above, the same site data, exposure assumptions, methodologies and approaches were used to estimate risk and hazards for all scenarios.

The remaining sections of this Revised Draft Final HHRA are organized as follows:

- Section 2 describes site features and summarizes environmental investigations performed at the site.

- Section 3 presents a risk characterization for the PPRTV scenario including subsections on exposure assessment, CSMs, data evaluation, quantification of exposure, toxicity assessment, risk estimates and uncertainties associated with the risk characterization.

- Section 4 presents a risk characterization for the ARCADIS Comparative Scenario including subsections on exposure assessment, CSMs, data evaluation, quantification of exposure, toxicity assessment, risk estimates and uncertainties associated with the risk characterization.

- ACLs are discussed in Section 5.

- Section 6 presents a complete list of the references cited in this Revised Draft Final HHRA.

2. Site Properties

This section presents an overview of site features and summarizes environmental investigations performed at the site. The site description is based on a review of historical records, maps and publicly available information; observations made during site visits; and data obtained during historical site investigations.

2.1 Site Location

The site is located on 240 acres just outside the city limits of North Pole, Alaska (the city). The city is located approximately 13 miles southeast of Fairbanks, Alaska, within Fairbanks North Star Borough (Figure 1-1).

2.2 Site Description

Three crude oil processing units and one sulfolane extraction unit are located in the southern portion of the site, making up the process area. Tank farms are located in the central portion of the site. Truck-loading racks are located immediately north of the tank farms and a railcar-loading rack is located west of the tank farms. Previously, a truck-loading rack was located between the railcar-loading rack and the tank farms, near the intersection of Distribution Street and West Diesel. Wastewater treatment lagoons, storage areas and two flooded gravel pits (the north and south gravel pits) are located in the western portion of the site. Rail lines and access roads are located in the northernmost portion of the site. An electrical generating facility (power plant) operated by Golden Valley Electric Association is located along the southern site boundary and is partially surrounded by the site. The power plant burns heavy aromatic gas oil (diesel 4) produced at the site. The property south of the site and the power plant is occupied by the Petro Star, Inc. Refinery. The Site Layout is presented on Figure 2-1.

North of the site are residential properties and the city's wastewater treatment plant (WWTP). The North Pole High School is located immediately north and west of the WWTP and residential properties. An undeveloped parcel, owned by the Alaska Department of Natural Resources, lies between the site and the WWTP. The Tanana River is located to the west, flowing in a northwesterly direction toward Fairbanks. East of the site is property that is residential or undeveloped, the Old Richardson Highway, the Alaska Railroad right-of-way and Chena Slough (known locally as Badger Slough).

2.3 Geology and Hydrogeology

This section summarizes geology and hydrogeology of the site based on information presented in previous site investigations and in the Site Characterization and First Quarter 2011 Groundwater Monitoring Report (Barr 2011).

2.3.1 Geology

The site and the area surrounding North Pole is located on the Tanana River Floodplain. The Beaver Springs Creek (also known as Thirtymile Slough) is located east of the site, with the shortest distance away at approximately 300 feet from the northeast corner of the site. The geology of the area is dominated by a thick sequence of unconsolidated alluvial deposits up to 600 feet thick. Discontinuous layers of silt, fine sandy silt and silty fine sand with occasional peat lenses have been encountered in the upper 10 feet of the unconsolidated sequence. Alluvial sand and gravel characterized as sandy gravels and gravelly sands, with occasional discontinuous lenses of sand, silt and organic deposits, are present below the silty layers. A ground-penetrating radar survey indicated the presence of silty layers in the shallow subsurface in onsite areas that were not identified through traditional drilling means. Onsite, these layers would likely influence the migration of constituents in the vadose and shallow saturated zones and may also influence onsite cleanup efforts. Data gathered during the planned soil investigation (described in the Site Characterization and First Quarter 2011 Groundwater Monitoring Report [Barr 2011]) were expected to provide additional information concerning the presence and potential influence of these layers. The results of the 2011 site characterization activities were reported in the Revised Site Characterization Report (Barr 2012). Soil borings installed in 2011 confirmed silty deposits in the vadose zone that were consistent with observations from previous investigations, including the 2010 ground penetrating radar study.

Permafrost has generally been identified using data from monitoring wells and private well installation logs. Top-of-permafrost depths ranged from 6 to greater than 150 feet below ground surface (bgs) in the study area. Residential well logs indicate that the bottom of the permafrost ranges from 14 to 245 feet bgs and that the thickness of the permafrost layer ranges from 5 to 232 feet. Moving northwest from the site, it appears that the top of the permafrost layer becomes shallower. The upper surface of the permafrost layer appears to be deepest near the site and also near Chena Slough. A “valley” in the upper surface of the permafrost layer appears to extend northwest from the site along Old Richardson Highway and the Alaska Railroad. Permafrost depth is likely to influence migration of sulfolane offsite. Additional data collection to further refine the understanding of the depth to and the location of permafrost is ongoing.

2.3.2 Hydrogeology

The site and the surrounding North Pole area are located on a relatively flat-lying alluvial plain that is situated between the Tanana River and Chena Slough. The site is located on the Tanana River Floodplain. Reference values of hydraulic conductivities of the aquifer materials range from 8 to 2,400 feet per day. Hydraulic conductivity estimates based on grain size range from 1 to 1,600 feet per day. Aquifer testing at the site in 2009 indicated a hydraulic conductivity of approximately 130 feet per day for wells screened in the upper 15 feet of the aquifer. This value was considered to be biased low because it was calculated with an aquifer thickness that did not account for the presence of permafrost. The geometric mean of

results from single-well pump testing conducted in 2011 indicated a hydraulic conductivity of 200 feet per day. Aquifer testing of the city's new water supply wells (installed in 2010) indicated a hydraulic conductivity ranging from approximately 700 to 1,100 feet per day based on pumping of wells screened from approximately 120 to 150 feet below the water table. The water table in the area is approximately 15 feet bgs and is usually present within the alluvial sand and gravel, and occasionally in the silty deposits. The water table decreases in elevation from southeast to northwest, mimicking the gradually decreasing elevation of the ground surface. Based on limited data, the water table has fluctuated vertically up to 4 feet since 2007. Seasonal lows typically occur any time from late March through May, with seasonal highs occurring in July or August.

Groundwater flow directions are primarily controlled by discharge from the Tanana River to the aquifer and from the aquifer to the Chena River and the Chena Slough. Variations in river stage are believed to be the primary cause of variations in flow direction. The flow direction trends to the north-northwest in the winter and spring and more northerly in the summer and fall.

2.4 Land Use and Beneficial Water Use

An active petroleum refinery is located onsite. Specifically, three crude oil processing units and associated utility and effluent buildings, maintenance and administrative buildings, warehouse, laboratory, chemical injection room and sulfolane extraction unit, three lagoons, north and south gravel pits, hazardous waste storage area, and multiple aboveground storage tanks (ASTs) occupy the site. The site is located within a fenced, guarded facility. The primary historical and current use of the site is commercial/industrial, which is not expected to change in the foreseeable future. FHRA does not have plans to redevelop the site.

Currently, no potable wells are present onsite and groundwater would only be used for onsite fire suppression purposes. The city supplies potable water to the site.

Offsite, downgradient to the north of the site is a mixed residential and commercial area. Currently, offsite residents and commercial workers located immediately north of the site obtain drinking water from the city's new water supply wells. Residents and commercial workers located outside the city water service area but within or near the dissolved sulfolane plume have been provided alternative water supplies (including treatment systems, bulk water tanks or continued supplies of bottled water) to eliminate potential ingestion of groundwater impacted with sulfolane. Bulk water tanks have also been provided to residents for irrigation of home gardens.

2.5 Current Site Remediation

FHRA is implementing the interim corrective actions described in the Interim Removal Action Plan (Barr 2010a) to optimize the existing groundwater pump and treat remediation system to aggressively address light nonaqueous phase liquid (LNAPL) and impacted groundwater onsite. Operation of the remediation system currently involves groundwater recovery from five recovery wells.

Installation and startup of the sand filters and a granular activated carbon (GAC) treatment system was completed during the second quarter 2011 and active operation was initiated on June 9, 2011. The sand filters and GAC filters were installed to treat dissolved-phase sulfolane concentrations in extracted groundwater.

FHRA continues to remove LNAPL from recovery and monitoring wells through active LNAPL pumping systems, passive LNAPL recovery measures and periodic manual removal. The recovered LNAPL is recycled within a refinery process unit.

2.6 Data from Previous Investigations

This section describes sources of analytical data that were used in the HHRA. Historical on- and offsite soil, groundwater and surface-water data are available. Additional soil and groundwater data were collected during the 2011 field season. Some surface-water (i.e., pore space) data were collected offsite during the 2012 field season. Installation methods for two of the three offsite locations needed to be revised because the adjacent surface water was frozen. As noted in Section 1, the groundwater collected adjacent to two of the three surface-water bodies in 2012 was likely not representative of the interface between groundwater and surface water and may overestimate the actual pore-water concentrations at those locations.

This Revised Draft Final HHRA evaluates data with complete Level II data packages received from the analytical laboratory through February 2012. SWI maintains the site database, which is built on a Microsoft® Access platform, and performs data validation consistent with ADEC requirements.

2.6.1 Soil Data

Historical soil data are summarized in the Site Characterization and First Quarter 2011 Groundwater Monitoring Report (Barr 2011). Historically, soil analytical data have been collected primarily at depths exceeding 2 feet bgs and include analyses for: gasoline range organics (GRO); diesel range organics (DRO); residual range organics (RRO); benzene, toluene, ethylbenzene and total xylenes (BTEX); polynuclear aromatic hydrocarbons (PAHs); volatile organic compounds (VOCs); semivolatile organic compounds (SVOCs); metals; and sulfolane (Barr 2011).

During the 2011 field season, surface soil samples were collected onsite and analyzed for historically detected constituents and additional COPCs. As discussed in Section 3.1.2.4 identified soil data gaps were filled during the 2011 field season following the approaches described in the Addendum (ARCADIS 2011b). The soil data collected during this sampling event were assessed for inclusion into this Revised Draft Final HHRA. Due to an inadvertent error, samples collected from the 2011 COPC soil borings were not submitted for analysis to determine concentrations of propylene glycol and isopropanol; instead, they were analyzed for the other COPCs identified in the RAWP.

Soil samples collected in 2010 for sulfolane analysis were validated by a third party, and final sulfolane concentrations identified by the validators were incorporated into the data set used for the HHRA. Based on the Level IV validation, it was determined that soil sample O-2 (7.5-9) should be considered unusable due to the very low internal standard area count and the high levels of petroleum hydrocarbon interference with all four sulfolane mass ions in the sample. This sample was not included in the Exposure Point Concentration (EPC) calculations. Validated data used in this Revised Draft Final HHRA were described in the Revised Site Characterization Report (Barr 2012) that was submitted to ADEC in March 2012.

2.6.2 Groundwater Data

Groundwater data have been collected onsite from 1987 to present and offsite from 2009 to present. Groundwater monitoring data collected during the most recent reporting period (fourth quarter 2011) are generally consistent with data collected during previous reporting periods (ARCADIS 2011c) and are summarized below:

- Dissolved-phase benzene concentrations up to 7,470 µg/L were detected during the fourth quarter 2011 in the sample collected from monitoring well MW-116.
- Dissolved-phase toluene concentrations up to 6,080 µg/L were detected during the fourth quarter 2011 in the sample collected from monitoring well MW-135.
- Dissolved-phase ethylbenzene concentrations up to 586 µg/L were detected during the fourth quarter 2011 in the sample collected from monitoring well MW-135.
- Dissolved-phase total xylenes concentrations up to 4,334 µg/L were detected during the fourth quarter 2011 in the sample collected from monitoring well MW-116.
- Sulfolane concentrations continue to be detected in both samples collected from onsite groundwater monitoring wells at concentrations up to 10,400 µg/L and in samples collected from offsite groundwater monitoring wells and residential wells at concentrations up to 443 µg/L.

Groundwater samples were collected for COPC analyses during the third and fourth quarter 2011 groundwater monitoring events. The full list of COPCs was not analyzed in third quarter 2011 samples because the complete COPC list (Table 3-2a) was not yet finalized. The complete COPC analytical suite was analyzed during fourth quarter 2011, with the exception of isopropanol and propylene glycol. These two COPCs will be analyzed during the first quarter 2012 groundwater monitoring event.

2.6.3 Surface-Water Data

As reported in the Site Characterization and First Quarter 2011 Groundwater Monitoring Report (Barr 2011), on August 11, 2010, surface-water samples were collected from the onsite north and south gravel pits and on October 10, 2010 from offsite Chena Slough, which runs parallel to Badger Road. The samples were analyzed for sulfolane. The laboratory reported that sulfolane was not detected above its limit of quantitation (LOQ) of 10 µg/L in either of the gravel pit samples or above the LOQ of 10.2 µg/L in the surface-water sample collected from Chena Slough.

FHRA conducted a pore-water investigation in 2012 to better characterize sulfolane concentrations in the groundwater/surface-water interface and the potential for surface-water sulfolane impacts. The planned approaches are described in the Addendum (ARCADIS 2011b). Some of the samples were collected when the adjacent surface-water body was frozen; therefore, the degree of connectivity with surface water, if any, could not be established. Because two of the collected samples likely reflect higher sulfolane concentrations than would be expected in true pore-water samples (because of limited surface-water to groundwater interchange), and because pore-water samples will generally reflect higher sulfolane concentrations than would be encountered by actual recreational users of the surface-water bodies due to degradation of sulfolane in surface water, the collected data are included in this Revised Draft Final HHRA.

The three offsite samples collected in March 2012 to assess surface-water risks were analyzed for sulfolane. The results are as follows: Pore-5 at <6.2 µg/L, Pore-4 at 28.7 µg/L and Pore-3 at 156 µg/L. Pore-5 was a true pore-water sample, but Pore-3 and Pore-4 were piezometer samples of groundwater that may not be representative of true pore water, because the adjacent surface-water body was frozen. The maximum detected concentration of sulfolane from these samples was used to assess potential recreational user exposures to sulfolane in surface water.

3. Provisional Peer Reviewed Toxicity Value Scenario

3.1 Exposure Assessment

ARCADIS conducted an HHRA to evaluate the potential for human health risk from exposure to site-related constituents, following protocols presented in the June 8, 2000 ADEC Risk Assessment Procedures Manual that are adopted into regulation in 18 AAC 75. The primary ADEC references for this Revised Draft Final HHRA include the Draft Risk Assessment Procedures Manual (ADEC 2010a and 2011d), Cleanup Levels Guidance (ADEC 2008a), Cumulative Risk Guidance (ADEC 2008b), and 18 AAC 75 Oil and Other Hazardous Substances Pollution Control guidance (ADEC 2008c). Other references used include RAGS (USEPA 1989, 1991, 2001, 2004a and 2009a), Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (USEPA 2002a), Vapor Intrusion Pathway: A Practical Guide (ITRC 2007a) and Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios (ITRC 2007b).

3.1.1 Human Health Conceptual Site Models

Two preliminary human health CSMs (one onsite CSM and one offsite CSM) were prepared and submitted to the ADEC with the Site Characterization Work Plan (Barr 2010b). After this submittal, a substantial amount of additional site assessment data was collected and in April 2011 the updated CSMs were submitted to the ADEC to reflect the enhanced understanding of site conditions. In the RAWP submitted to ADEC in December 2011 (ARCADIS 2011a), the CSMs were further refined to better reflect existing site conditions. The updated CSMs were developed following the Human Health Conceptual Site Model Graphic and Scoping Forms and the Policy Guidance on Developing Conceptual Site Models (ADEC 2010b and 2010c, respectively). Due to the significant difference in COPC occurrence onsite (petroleum hydrocarbon constituents and sulfolane) versus offsite (sulfolane only), two human health CSM graphic forms (Figures 3-1 and 3-2) were prepared and updated to more clearly portray and distinguish potential exposure pathways for possible on- and offsite receptors.

This section describes the CSMs submitted to the ADEC in December 2011 and revisions to the offsite CSM based on ADEC comments discussed during the meeting held on January 24, 2012. Human health CSMs for on- and offsite locations are presented on Figures 3-1 and 3-2, respectively, and are discussed in the following subsections.

3.1.1.1 Potential Sources

During site operations, various materials associated with the crude oil refining process have been released in operating areas of the site, including the crude oil processing units, extraction unit, loading racks, wastewater lagoons, sumps and drain systems. In addition, spills and/or leaks to surface soil from ASTs, pumps and associated piping during routine operations constitute potential sources of petroleum

constituents at the site. Petroleum hydrocarbons have also been detected in historical groundwater samples collected from onsite monitoring wells.

Onsite impacted environmental media may include surface (0 to 2 feet bgs) and subsurface (to a depth of 15 feet bgs, the maximum depth at which human exposure is likely to occur) soil, groundwater, indoor and outdoor air, surface water, sediment and biota. Offsite impacted media may include groundwater, surface water, sediment, wild food (such as fish) and homegrown produce.

3.1.1.2 Potential Fate and Transport Mechanisms

As described in Section 3.1.1, the primary sources of COPCs are spills and releases to soil and groundwater during facility operations. COPCs may be retained in site soils or subject to constituent fate and transport mechanisms at the site. Fate and transport mechanisms may include soil sorption; biodegradation; wind erosion and transport; migration to groundwater; advective/dispersive transport in groundwater, on or offsite; and volatilization into soil gas, outdoor air or indoor air.

Potential current and future onsite receptors may be directly exposed to COPCs in surface and subsurface soil via incidental ingestion, dermal contact and inhalation of dust particles in air. In addition, COPCs adhered onto dust particles may migrate from exposed surface or subsurface soil to outdoor air and be breathed by potential offsite receptors. When bound to surface soils, compounds sorbed to soil particles may be subject to wind erosion and windblown transport in outdoor air. Due to the nature of the site, the majority of operational areas are covered with asphalt pavement or gravel. However, exposed and unpaved areas do exist at the site. Therefore, although limited, windborne particulate transport is possible at the site, and this potential pathway was evaluated during the HHRA.

COPCs may leach from soil to groundwater by percolation or may have been directly released to groundwater. Based on groundwater samples collected from onsite wells, sulfolane is the only COPC that is known to have migrated offsite. Potential direct-contact exposures to COPCs in groundwater (e.g., tapwater ingestion and inhalation of volatiles in water) are not expected to occur for current and future onsite commercial/industrial workers because onsite groundwater is only used for industrial purposes (e.g., fire suppression). However, current and future onsite outdoor commercial/industrial receptors may be exposed to COPCs in groundwater by dermal contact while extinguishing fires, if they occur. In addition, due to the relatively shallow average depth to groundwater onsite (historically from 8 to 10 feet bgs), current and future onsite construction/trench workers may be exposed by incidental ingestion of and dermal contact with COPCs in groundwater that has pooled in excavated trenches.

The city provides municipal water for drinking and other potable uses at the site. Current onsite receptors consume drinking water from a municipal source and are expected to consume drinking water from this source in the future. Current and future offsite receptors may be exposed to sulfolane in groundwater that

has migrated from the site to wells used for tapwater. In addition, groundwater may be used offsite to irrigate homegrown produce. Sulfolane in groundwater may be taken up by homegrown produce and consumed by offsite residents.

Onsite surface water consists of water that is stored in two lagoons and two gravel pits. Runoff and erosion from soil to surface water may be transport mechanisms. Groundwater from the site flows offsite in a north-northwesterly direction and groundwater is recharged by surface water from the Tanana River. COPCs in groundwater may eventually flow to offsite surface-water bodies and to sediment, which may be contacted by offsite recreational users. Pore-water data were collected to evaluate the potential for exposure at the groundwater/surface-water interface. Some of the samples used for this HHRA were collected when the adjacent surface-water body was frozen; therefore, the degree of connectivity with the surface water, if any, could not be established.

For this HHRA, potential ingestion of sulfolane in surface water by adult and child recreational users while swimming is considered a potentially complete exposure pathway offsite. The collected pore-water samples likely reflect higher sulfolane concentrations than would be expected in true pore-water samples because of limited surface water to groundwater interchange during frozen conditions. Pore-water samples will generally reflect higher sulfolane concentrations than would be encountered by actual recreational users of the surface water bodies because sulfolane degrades more rapidly in the presence of nutrients and oxygen that would be present in the surface water (ADHSS 2010). Accordingly, the data used in the surface-water evaluation in this Revised Draft Final HHRA provide a health-protective assessment of risk to swimmers.

Volatilization is another fate and transport mechanism at the site for lighter petroleum hydrocarbon compounds and other VOCs. VOCs may volatilize from subsurface soil into soil gas, with eventual diffusion and/or advection into outdoor air and/or indoor air in onsite buildings. VOCs may also leach from soil to groundwater, where dissolved-phase VOCs may be transported downgradient both on and offsite. VOCs may volatilize from shallow exposed groundwater in excavations directly into outdoor air. VOCs may volatilize from groundwater into soil gas, with eventual diffusion and/or advection into outdoor air and/or indoor air of on- and/or offsite buildings. VOCs may also be subject to degradation by microorganisms in subsurface soils and groundwater. Heavier petroleum hydrocarbon compounds, such as PAHs, adsorb to solids and do not tend to volatilize. As such, these compounds generally tend to remain in place, where they are subject to aerobic biodegradation by microorganisms. Sulfolane is not expected to volatilize under the conditions observed at the site, as discussed in Section 3.1.1.4.

3.1.1.3 Potential Receptors

Potential human receptors were identified based on current and reasonably foreseeable future land use at the site. A review of current and future land use identified the following potential human receptors at the site.

- **Current and future onsite indoor commercial/industrial workers** were considered to be individuals from 18 to 65 years old. It was assumed that these receptors perform commercial and/or industrial work activities (e.g., office work, laboratory analyses, shipping or warehouse inventory management) indoors onsite, under current or future (redeveloped) land use scenarios. Potential exposures to COPCs in soil are considered to be insignificant for onsite indoor commercial/industrial workers. These potential receptors may be exposed to COPCs in indoor air during a standard 40-hour work week for 25 years, for 250 days per year. Potential inhalation of outdoor air is insignificant. Inhalation of VOCs in indoor air was evaluated following USEPA (2009a) RAGS Part F.

- **Current and future onsite outdoor commercial/industrial workers** were considered to be individuals from 18 to 65 years old. These receptors were assumed to perform commercial and/or industrial work activities (e.g., maintenance work for ASTs or associated piping) outdoors at the site under current or future (redeveloped) land use scenarios. These individuals may occasionally use site groundwater for industrial purposes (e.g., fire suppression). Direct-contact exposures with groundwater are considered insignificant because fires are rare onsite and the exposure period is expected to be short. This exposure pathway was not quantitatively evaluated. These potential receptors may be exposed to COPCs in site media during a standard 40-hour work week for 25 years, for 250 days per year. Following ADEC (2010a) guidance, it was assumed that onsite outdoor workers with an average body weight (BW) of 70 kilograms (kg) are exposed to 100 milligrams per day (mg/day) COPCs in surface soil and that 100 percent of the fraction ingested (FI) is from onsite surface soil.

  FHRA requires all onsite workers to wear long-sleeved shirts, long pants and shoes. Thus, the adult commercial/industrial worker outdoor receptor was assumed to wear a long-sleeved shirt, long pants and shoes, which limits the exposed skin surface to the head and hands. The recommended USEPA (2011a) skin surface area (SSA) exposed to impacted soil for the adult commercial/industrial worker outdoor receptor is 2,230 square centimeters (cm^2), which is the average of the adult male and adult female mean values for head and hands. The USEPA (2004a) recommended weighted soil-to-skin adherence factor (AF) for a commercial/industrial adult worker of 0.2 milligram per square centimeter (mg/cm^2) based on the 50^{th} percentile weighted AF for utility workers (i.e., the activity determined to represent a high-end contact activity) was used. Potential inhalation of indoor air was considered insignificant for the outdoor commercial/industrial worker. Inhalation of volatile COPCs and dust in outdoor air was evaluated following USEPA (2009a) RAGS Part F.

- **Current and future onsite construction/trench workers** were considered to be individuals from 18 to 65 years old. These receptors were assumed to perform short-term maintenance and emergency repair activities on underground utilities or facility piping at the site. These receptors may be exposed to COPCs in surface and/or subsurface soil during the work day while performing the maintenance and/or repair task. Because the depth to groundwater at the site generally ranges from 8 to 10 feet bgs, construction/trench workers may be exposed to COPCs in groundwater that has pooled in a trench during performance of the maintenance and/or repair task. It was assumed that the same worker will provide maintenance and/or repair tasks.

  Potential construction/trench worker receptors were assumed to be exposed to COPCs in onsite soil (down to a depth of 15 feet bgs) and groundwater for 1 hour each day of a standard 5-day work week, for 125 days, for 1 year. This exposure frequency (EF) is a modification from that proposed in the RAWP (250 days per year). This deviation is justified because most of the utilities at the site are located aboveground and trenching activities typically do not occur during 6 months of each year, when the ground is frozen. It is assumed that soil may be accessible for trenching activities (i.e., not frozen) for 6 months per year.

  Construction/trench workers with an average BW of 70 kg are assumed to be exposed to 330 mg/day (USEPA 2002b) of COPCs in surface and subsurface soil, and 100 percent of the FI is assumed to be from surface and subsurface soil. It was assumed that onsite construction/trench workers incidentally ingest 0.0037 liter per day (L/day) of groundwater pooled in a trench. This rate is based on the mean ingestion rate for wading/splashing presented in the USEPA (2011a) Exposure Factors Handbook (EFH) Table 3-93 (3.7 milliliters per hour * 1 hour per day). This consumption rate is likely to overestimate actual exposure, because dewatering usually occurs at excavation sites where water has pooled in trenches.

  FHRA requires all onsite workers to wear long-sleeved shirts, long pants and shoes. Therefore, the onsite adult construction worker receptor was assumed to wear a long-sleeved shirt, long pants and shoes, and the exposed SSA was limited to the head and hands. The USEPA (2011a) recommended SSA exposed to impacted soil for the adult construction worker receptor is 2,230 cm^2. The USEPA (2002b) recommended weighted soil-to-skin AF for a construction worker of 0.3 mg/cm^2-day was used. Inhalation of volatile COPCs and dust in outdoor air were evaluated following USEPA (2009a) RAGS Part F.

- **Current and future onsite visitors and trespassers.** Occasional visitors or trespassers may also be present onsite. However, the site does not and is not expected to attract trespassers because of the character and location of the site (i.e., an industrial setting with controlled access). Moreover, it is anticipated that a trespasser's exposure at the site would be very infrequent. Onsite visitors are typically adults with limited access across the site. Children rarely visit the site. Thus, potential direct-

contact exposures to COPCs in soil and groundwater by current and future onsite trespassers and visitors are insignificant. Potential inhalation of outdoor air is also insignificant. However, assuming the adult visitor is located in an onsite building, inhalation of volatile COPCs in indoor air by this potential receptor was evaluated following USEPA (2009a) RAGS Part F. Current and future onsite adult visitors (18 to 65 years of age) are assumed to be exposed to COPCs in indoor air for 2 hours per day, 12 days per year for 30 years.

- **Current and future offsite residents** were evaluated as infants (0 to 1 year of age), children (0 to 6 years of age) and adults (18 to 65 years of age). HHRAs do not typically focus on infant exposures as a separate receptor group, but infants are included here because the Agency for Toxic Substances and Disease Registry (ATSDR 2011) and the State of Alaska Department of Health and Social Services (ADHSS 2012) have addressed infants as a separate receptor group in their Health Consultations. There is evidence that sulfolane does not present a significant risk for developmental effects and it is not mutagenic, mitigating infant-specific exposure concerns. Resident receptors were assumed to be located downgradient of the site and may be exposed to sulfolane in groundwater that has migrated from the site. No other COPCs associated with site operations are known to be present in offsite groundwater. These potential offsite receptors may ingest sulfolane in groundwater as tapwater. In addition, it was assumed that these potential receptors consume homegrown produce, which may have taken up sulfolane from groundwater. It was assumed that potential resident receptors may be exposed to sulfolane in tapwater for a 1-, 6- and 30-year duration for infants, children and adults, respectively, for 350 days per year.

  Current and future offsite adult, child and infant residents may also inhale dust from the site. Inhalation of dust in outdoor air by these potential receptors was evaluated following USEPA (2009a) RAGS Part F.

  Following ADEC (2010a) guidance, it was assumed that 70 kg adult residents consume 2 L/day of tapwater. Following USEPA (1989) guidance, it was assumed that 15 kg child residents consume 1 L/day of tapwater. Infants were assumed to weigh an average of 6.75 kg (the average of the age-group specific mean values from 0 to 1 year) and to consume 1.05 L/day (the time-weighted average of the *per capita* age-group-specific 95th percentile values from 0 to 1 year) of tapwater based on USEPA (2011a) guidance. The groundwater ingestion exposure parameters for infants likely overestimate potential exposure, because it was assumed that they do not breastfeed and do not consume formula made with distilled water (a typical pediatric guideline for the first several months of life).

  Fractions of homegrown fruit and vegetables ingested, water-to-produce bioconcentration factors and ingestion rates for offsite adult and child residents for the PPRTV scenario are discussed in Section 3.1.3.1.6.

- **Current and future offsite indoor and outdoor commercial/industrial workers** were considered to be individuals from 18 to 65 years old. It was assumed that these potential receptors perform commercial and/or industrial work activities indoors or outdoors at offsite locations under current or future land use scenarios during a standard 40-hour work week for 25 years, for 250 days per year. These receptors may ingest sulfolane in groundwater as tapwater. Following ADEC (2010a) guidance, it was assumed that 70 kg offsite adult commercial/industrial workers consume 2 L/day of tapwater. In addition, they may inhale dust that may have been released onsite via wind erosion. Potential exposures to COPCs in dust were considered to be insignificant for offsite indoor commercial/industrial workers. Inhalation of dust in outdoor air by outdoor commercial/industrial workers was evaluated following USEPA (2009a) RAGS Part F.

- **Current and future offsite recreational users.** Sulfolane may potentially migrate offsite via groundwater to surface water and to sediment in downgradient surface-water bodies. Access to downgradient, offsite surface-water bodies is minimal due to surrounding industrial land use and hazardous physical conditions, and direct contact with surface water and sediment by human receptors is limited. Regardless, for this HHRA, ingestion of surface water by offsite adult and child recreational users while swimming is considered a potentially complete exposure pathway. Recreational user exposure assumptions for the PPRTV scenario are discussed in Section 3.1.3.3.

- **Current and future offsite construction/trench workers** were considered to be individuals from 18 to 65 years old. These receptors were assumed to perform short-term maintenance and emergency repair activities on underground utilities at offsite properties. These potential receptors may be exposed to sulfolane in groundwater that has pooled in a trench during performance of the maintenance and/or repair task. It was assumed that offsite construction/trench workers incidentally ingest 0.0037 L/day of groundwater pooled in a trench. This rate is based on the mean ingestion rate for wading/splashing presented in the USEPA (2011a) EFH Table 3-93 (3.7 milliliters per hour * 1 hour per day). This consumption rate overestimates actual consumption, because dewatering usually occurs at excavation sites where water has pooled in trenches. It was conservatively assumed that the same worker performs multiple maintenance and/or repair tasks. These potential receptors (70 kg for adults) may be exposed to sulfolane in groundwater for 1 hour each day of a standard 5-day work week, for 125 days per year, for 1 year.

3.1.1.4 Exposure Pathway Evaluation

Potential exposure pathways selected for quantitative evaluation are shown in the on- and offsite human health CSMs. An exposure pathway was retained for further evaluation if it was considered potentially complete. Each of the following components must be present in order for an exposure pathway to be considered complete (USEPA 1989):

- Source and/or constituent release mechanism
- Retention or transport medium
- Receptor at a point of potential exposure
- Exposure route at the exposure point.

Complete exposure pathways were evaluated for identified COPCs. Only potential ingestion exposures were quantitatively assessed for sulfolane. Dermal contact and inhalation exposure routes are not significant for sulfolane. The ATSDR (2010 and 2011) Health Consultations support these conclusions. Animal studies have shown that sulfolane is not readily absorbed through human skin because of its low permeability (Brown et al. 1966) and is not expected to pose a significant risk via an inhalation exposure route due to its low volatility (Andersen et al. 1977). Brown et al. (1966) studied the skin and eye irritant and skin sensitizing properties of acute exposures to sulfolane on two animal species. This study concluded that sulfolane did not irritate or sensitize the skins of guinea pigs or rabbits and, undiluted, was only very mildly irritating on the eyes of rabbits.

Andersen et al. (1977) conducted acute and subacute investigations of the inhalation toxicity of sulfolane on four animal species including monkey, dog, guinea pig and rat. A no-observed-effect level for sulfolane of 20 mg/m^3 was reported, and the authors concluded that airborne concentrations of sulfolane as high as those investigated are unlikely to be encountered on any but an emergency basis. Andersen et al. (1977) reported that sulfolane has a relatively low vapor pressure (approximately 0.13 millimeter of mercury at 32 degrees Celsius [°C]) and only unusual conditions would produce an extensive release of aerosolized sulfolane. Andersen et al. (1977) further noted that if sulfolane is handled at room temperature in an area with proper ventilation, it should not be regarded as posing an unusual hazard.

Potentially complete and significant exposure pathways were identified for the following receptors, with the exception that dermal and inhalation exposures to sulfolane are incomplete (as noted above):

- Onsite indoor commercial/industrial worker (current and future):
  - Inhalation of volatile COPC vapors in indoor air from groundwater.
- Onsite outdoor commercial/industrial worker (current and future):
  - Ingestion of, dermal contact with and inhalation (particulates) of COPCs in surface soil.
  - Dermal contact with COPCs in groundwater while extinguishing fires was qualitatively evaluated.
  - Inhalation of volatile COPC vapors in outdoor air volatilized from surface and subsurface soil and groundwater.

- Onsite construction/trench worker (current and future):
  - Ingestion of, dermal contact with and inhalation (particulates) of COPCs in surface and subsurface soil.
  - Inhalation of volatile COPC vapors in trench air from surface and subsurface soil and groundwater.
  - Ingestion of and dermal contact with COPCs in groundwater in excavation trenches.
- Onsite adult visitor (current and future):
  - Inhalation of volatile COPC vapors in indoor air from groundwater.
- Offsite adult, child and infant residents (current and future):
  - Ingestion of sulfolane in groundwater (i.e., tapwater).
  - Ingestion of homegrown produce irrigated with sulfolane-impacted groundwater.
  - Inhalation of fugitive windborne dust from onsite COPCs in surface soil.
- Offsite indoor and outdoor commercial/industrial worker (current and future):
  - Ingestion of sulfolane in groundwater (i.e., tapwater).
  - Inhalation of fugitive windborne dust from onsite COPCs in surface soil (outdoor worker only).
- Offsite construction/trench worker (current and future):
  - Ingestion of sulfolane in groundwater (i.e., in excavation trenches).
- Offsite adult and child recreational users (current and future):
  - Ingestion of sulfolane in surface water (i.e., pore water).

3.1.2 Data Evaluation, Constituent of Potential Concern Selection and Identification of Data Gaps

The proposed methods for data evaluation, identification of data gaps, selection of COPCs and proposed sampling to address data gaps are discussed below. Both maximum and 95% upper confidence limit (95% UCL) on the mean constituent concentrations for groundwater were evaluated.

3.1.2.1 Data Evaluation

The available data that were used include analytical results from soil investigations conducted at the site since 2001. Data from four sets of soil samples were evaluated, including samples collected in March and May 2001, July 2004, October 2010 and October 2011. One soil sample collected in 2010 (O-2 [7.5-9]) was determined to be unusable in a Level four data validation, so this sample was not included in EPC calculations.

Groundwater and surface-water data collected during the last 2 years were also included. SWI provided the soil and groundwater analytical data used in the HHRA in an electronic format. Initially, the data were separated into individual datasets by environmental media, including: onsite groundwater, offsite (downgradient) groundwater, onsite surface soil (0 to 2 feet bgs) and onsite subsurface soil (2 to 15 feet bgs).

The quality of the data is acceptable for risk assessment use. Parameters evaluated in the data quality assessment include spatial and vertical coverage and representativeness of sampling locations, analytical methods and reporting limits used by the laboratories, and data qualifiers applied during data validation. The HHRA relies on validated data supplied by SWI as presented in the Revised Site Characterization Report (Barr 2012). Data collected for this evaluation were collected per ADEC-approved sampling and analysis plans. Consideration was given to the recently developed standard procedure for analyzing sulfolane in groundwater (isotope dilution) and the historical variability between analytical results. The data relied upon in this risk assessment met the following criteria for data usability for risk assessment as recommended in ADEC (2010a) guidance:

- Analytical data sufficient for adequate site characterization were available.
- Data were collected consistent with ADEC and USEPA guidance.
- Sampling and analytical procedures gave accurate constituent-specific concentrations.
- Level two data validation was performed on analytical laboratory data used for this evaluation. Validation reports for the 2011 soil and groundwater data, and for the 2012 pore-water data prepared

by SWI, were included in the Revised Site Characterization Report (Barr 2012). Level four data validation was performed on the 2010 sulfolane in soil analyses.

- Method detection limits and sample quantitation limits were below screening criteria.
- Qualified data were used in the risk assessment; potential bias from qualified data and how it might result in an over or under estimation of risk is discussed in Section 3.5.
- Rejected data were not used for risk assessment purposes.
- For a given well, if all samples were reported as non-detects, then the lowest detection limit associated with any sampling event at that well was used to represent the well.
- If a well had both detected concentrations and reported non-detects for a given COPC, then the non-detect was represented by a value equal to one-half the detection limit associated with that COPC in that sampling event.

Offsite groundwater has been sampled at monitoring wells and private residential wells. At the request of ADEC, the off-site area was delineated into smaller exposure units (EUs) for the purposes of the 95% UCL evaluation. Accordingly, ARCADIS developed three separate exposure units (e.g., Exposure Unit 1 [EU-1], Exposure Unit 2 [EU-2] and Exposure Unit 3 [EU-3]) for statistical evaluation. These EUs were based on estimated sulfolane isocontour lines developed from fourth quarter 2011 groundwater sampling data, and generally reflect spatially contiguous areas that represent certain ranges of concentration and portions of the sulfolane plume in groundwater. Some data points outside of the concentration range are present within each of the defined EUs and are the result of data collected from well screens of varying depths. These data points were included in the analysis, because it is reasonable to assume that any hypothetical exposures to water from drinking water wells within any given unit may also include exposures to groundwater generated at varying depths. The EUs are bounded by the concentration contours of greater than (>) 100 µg/L, >25 µg/L and detectable sulfolane (Figure 3-3). These contour intervals were selected and drawn using the combined offsite well data set and are based on best professional judgment. Guidance presented in the Data Quality Assessment: Statistical Methods for Practitioners (USEPA 2006a) was considered during selection of the off-site groundwater dataset(s). The data from wells within a given EU were used to estimate the 95% UCL on the mean concentration as a health-protective and representative EPC. ProUCL version 4.1 (USEPA 2011b) was used to derive the 95% UCL on the mean of the constituent concentrations.

The utility of the soil and groundwater analytical data identified in the SWI (2000 and 2001) contaminant characterization studies conducted for the site was evaluated for the HHRA. The characterization study conducted at the site in 2001 was performed to collect additional soil and groundwater data to address data

gaps from the site investigation conducted in 2000. In general, for both media, the analytical methods used included those for GRO, DRO, RRO, BTEX, selected metals, VOCs, SVOCs and sulfolane (for groundwater only).

3.1.2.2 Constituents of Potential Concern

COPCs have been identified from a list of potential constituents of interest (COIs), such as those that were likely used or spilled at the site. COPCs for each dataset were carried through the HHRA process.

Preliminary lists of COIs and COPCs in soil and groundwater at the site were presented in the Site Characterization and First Quarter 2011 Groundwater Monitoring Report (Barr 2011). The lists were revised in the Addendum (ARCADIS 2011b) based on the ADEC (2011a) Comment Matrix on the site characterization report. The lists of preliminary COIs and COPCs were also presented in the RAWP (ARCADIS 2011a).

As noted in the RAWP (ARCADIS 2011a), the list of COIs was developed according to the following process:

1. FHRA compiled a list of spills based on staff interviews, refinery records and a review of spill records retained by the ADEC.

2. The list of spills was refined by eliminating:

    a. Spills less than 10 gallons.
    b. Spills that were reportedly contained.
    c. Spills that were remediated and had confirmation sampling.

For many spills on the list, the material spilled was specific to one ingredient (e.g., propylene glycol) or was a material with obvious and limited ingredients (e.g., kerosene). However, the individual ingredients (e.g., oily water) of the other materials reportedly spilled were not provided. Refinery specialists such as chemists, wastewater experts and production leads were consulted to apply operational knowledge of the refinery to determine the ingredients that made up this set of materials. By this process, the list of spills was then distilled down to the “ingredients” or the primary constituents that make up the material spilled. This ingredient list was also compared to constituents that had been included in laboratory analyses of facility wastewater. The resulting ingredient list was then used to make up a list of COIs for the site. The COI list also included constituents that were analyzed during previous site characterization studies, regardless of whether they were detected above the practical quantitation limit (PQL). The list of COIs for the site is shown in Table 3-1. Constituents in the ingredient list that were analyzed for but not detected were not removed from this list. If a constituent was previously detected at the site and/or was included in the ingredient list, it was considered a COI.

Table 3-1 indicates if a constituent was previously analyzed in soil or groundwater samples collected at the site. Table 3-1 also indicates if a constituent was included in the ingredient list; the last four columns of the table summarize whether toxicity data are available from the USEPA's Integrated Risk Information System ([IRIS]; USEPA 2012a).

For this Revised Draft Final HHRA, maximum detected concentrations and/or the laboratory reporting limits of COIs in soil and groundwater are compared with ADEC screening levels corresponding to a 1×10^{-6} target excess lifetime cancer risk (ELCR) and 0.1 target hazard quotient (HQ), as shown in Table 3-2a. COI soil concentrations were compared with ADEC screening levels protective of potential migration to groundwater based on a zone with less than 40 inches of annual precipitation, direct-contact exposures and outdoor inhalation (ADEC 2008a [Table B-1 of 18 AAC 75, Method Two]). If ADEC soil screening levels were unavailable, then COI concentrations in soil were compared with USEPA Regional Screening Levels ([RSLs]; USEPA 2011c), adjusted to a target ELCR of 1×10^{-6} (if necessary) and a HQ equal to 0.1, for the applicable exposure pathway. Soil screening levels for GRO, DRO and RRO were from ADEC (2008a) Table B-2 Method Two. COI groundwater concentrations were compared with ADEC groundwater screening levels (ADEC 2008a; Table C). If ADEC groundwater screening levels were unavailable, then COI concentrations were compared with USEPA RSLs (USEPA 2011c) based on tapwater ingestion.

The higher of either the maximum COI concentration detected above the laboratory reporting limit or maximum detection limit was compared with the selected ADEC screening levels. The selected soil screening levels were based on the lesser of the migration to groundwater, $^{1}/_{10}$ the direct contact or $^{1}/_{10}$ the outdoor air screening levels. COIs with concentrations exceeding the selected soil screening level were identified as COPCs. Table 3-2a lists the COPCs identified in soil and groundwater based on ADEC (2010a) COPC selection guidance applied to the COIs identified in Table 3-1.

The preliminary COPCs identified at the site, as presented in Table 3-2a, are COIs that were detected in site media and exceeded ADEC screening levels. COIs not detected in site media but that had practical quantitation limits exceeding ADEC screening levels and COIs identified by the refinery as ingredients that could have been released are also considered COPCs. Arsenic was eliminated as a COPC in groundwater based on published background concentrations for the area of the site (U.S. Geological Survey 2001). However, it was retained as a COPC in soil in the RAWP (ARCADIS 2011a). An evaluation of the 2011 arsenic in soil data was presented in the Revised Site Characterization Report (Barr 2012). Based on this evaluation, it is likely that the presence of detectable arsenic in soil samples collected at the site is attributable to background concentrations. No other metal COIs were eliminated from the list of COPCs based on background concentrations. In accordance with ADEC (2010a) guidance, Table 3-2a has been provided to the ADEC in Microsoft® Excel format.

Table 3-2b summarizes COPCs by environmental media.

3.1.2.3 Data Gaps

Based on a review of the preliminary human health CSMs and available analytical data for environmental samples collected at the site, and discussions held during the June 24, 2011 Risk Assessment Scoping Meeting, four potential risk assessment data gaps were indicated:

- Limited surface soil data were available for the evaluation of potential risks and hazards to onsite human receptors.
- Onsite containment of COPCs other than sulfolane must be supported.
- Possible connection between groundwater at the site and surface water must be determined.
- No soil gas data were available to evaluate onsite vapor intrusion concerns.

3.1.2.4 Sampling Plans to Address Data Gaps

Sampling plans for additional data collection are described in the Addendum (ARCADIS 2011b). With respect to risk assessment data gaps identified in Section 3.1.2.3, the following field activities have been conducted:

- Onsite soil assessment activities, to characterize soil impacts and provide data for risk assessment activities. The soil data collected in 2011 adequately characterized the nature and extent of surface and subsurface impacts for the purposes of this HHRA evaluation. Additional sampling is planned for 2012 to complete characterization for the purposes of a remediation feasibility study. The 2011 soil data were validated and included in this evaluation.
- Additional groundwater sampling, during the third and fourth quarters 2011, confirmed that no other COPCs (except sulfolane) have migrated offsite.

A pore-water investigation was conducted to better characterize sulfolane concentrations in the groundwater/surface-water interface and the potential for surface-water sulfolane impacts. The March 2012 samples were collected when the adjacent surface-water body was frozen; therefore, the degree of connectivity with surface water, if any, could not be established. Therefore, the piezometer samples were likely more representative of groundwater. Because sulfolane degrades more rapidly in the presence of nutrients and oxygen that would be present in the surface water (ADHSS 2010), the groundwater collected adjacent to two of the three surface-water bodies in 2012 likely overestimates surface water concentrations at those locations. The data presented in this Revised Draft Final HHRA provide a health-protective estimate of risk to swimmers.

Soil gas data were not collected to evaluate potential vapor intrusion concerns. Instead, onsite groundwater data were used to evaluate the vapor intrusion exposure pathway. All onsite groundwater analytical data collected during the last 2 years (2009 through 2011) were used to predict indoor air concentrations of volatile COPCs and to estimate risks and hazards to current and future onsite indoor commercial workers. The maximum detected groundwater concentration for each COPC was used as the source term for Johnson & Ettinger (J&E) groundwater-to-indoor air modeling (USEPA 2004b) in the maximum exposure scenario. The 95% UCL concentration calculated from the average concentration in each onsite well was used as the source term in the 95% UCL scenario.

3.1.3 Quantification of Exposure

The objective of the exposure assessment was to estimate the type and magnitude of potential receptor exposure to COPCs. Results of the exposure assessment were then combined with constituent-specific toxicity values in the toxicity assessment (see Section 3.2) to characterize potential risks (USEPA 1989).

3.1.3.1 Dose/Intake Equations

Exposures were quantified using standard exposure equations consistent with RAGS (USEPA 1989, 1991, 2004a and 2009a) for the potentially complete exposure pathways identified in Section 3.1.1.4.

The general algorithms presented below were used to estimate the lifetime average daily dose (LADD) for carcinogenic compounds and the average daily dose (ADD) for noncarcinogenic COPCs for direct-contact pathways (i.e., ingestion and dermal contact) by combining environmental media concentrations with the receptor-specific exposure parameters that constitute "intake factors." Both the ADD and the LADD are in units of milligrams per kilogram per day (mg/kg-day) (USEPA 1989). For inhalation exposure pathways, exposure was estimated as an average exposure concentration (AEC) for noncarcinogenic COPCs or lifetime average exposure concentration (LAEC) for carcinogenic COPCs. Both the AEC and the LAEC are in units of milligrams per cubic meter (mg/m^3) (USEPA 2009a).

The dose equations and parameter descriptions used are provided in the following subsections.

3.1.3.1.1 Incidental Ingestion of Soil

The doses of COPCs associated with incidental ingestion of soil were calculated as follows:

$$\text{Dose} = \frac{EPC_s * IR_s * FI * EF * ED * CF}{BW * AT} * RAF$$

Where:

Dose = ADD or LADD (mg/kg-day)

EPC_s = EPC in soil (milligrams per kilogram [mg/kg])

IR_s = soil ingestion rate (milligrams soil per day)

FI = fraction ingested (unitless)

EF = exposure frequency (days per year)

ED = exposure duration (years)

CF = conversion factor ($1x10^{-6}$ kilograms per milligram [kg/mg])

BW = body weight (kg)

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

RAF = relative absorption factor (unitless), assumed to equal 1

The USEPA (1989) defines FI as a "pathway-specific" value that should be applied to consider constituent location and population activity patterns. FI accounts for the fraction of the site covered with asphalt or vegetation, which reduces potential exposure. Following the ADEC's (2010a) guidance, an FI of 1 was assumed for the current and future onsite outdoor commercial/industrial worker and future onsite construction/trench worker, despite the fact that much of the site is covered with asphalt and buildings.

3.1.3.1.2 Dermal Contact with Soil

Absorbed doses of constituents associated with dermal contact with soil were calculated as follows:

$$Dose = \frac{EPC_s * SSA_s * AF * FC * ABS_d * EV_s * EF * ED * CF}{BW * AT}$$

Where:

Dose = ADD or LADD (mg/kg-day)

EPC_s = EPC in soil (mg/kg)

SSA_s = SSA available for contact (cm^2/event)

AF = soil-to-skin adherence factor (mg/cm^2-event)

FC = fraction in contact with soil (unitless)

ABS_d = dermal absorption factor (unitless)

EV_s = event frequency (soil) (events/day), assumed to be 1 per day unless otherwise noted

EF = exposure frequency (days/year)

ED = exposure duration (years)

CF = conversion factor ($1x10^{-6}$ kg/mg)

BW = body weight (kg)

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

Constituent-specific dermal parameters, such as SSA_s, AF and ABS_d were provided from USEPA (2004a) RAGS Part E. ABS_d are presented in Table 3-13.

Similar to FI for the soil ingestion pathway, FC was added to the dermal contact equation to account for the fraction of the site covered with asphalt or vegetation, which reduces potential exposure. Following the ADEC's (2010a) guidance, an FC of 1 was assumed for the current and future onsite commercial/industrial worker and future onsite construction/trench worker.

3.1.3.1.3 Ingestion of Groundwater

The doses of COPCs associated with ingestion of groundwater were calculated as follows:

$$\text{Dose} = \frac{EPC_w * IR_w * EF * ED}{}$$

$$\frac{}{BW * AT}$$

Where:

Dose = ADD or LADD (mg/kg-day)

EPC_w = EPC in water (milligrams per liter [mg/L])

IR_w = water ingestion rate (liters water/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight (kg)

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

3.1.3.1.4 Dermal Contact with Groundwater

Absorbed doses of constituents associated with dermal contact with groundwater were calculated as follows:

$$Dose = \frac{DA_{event} * SSA_w * EV_w * EF * ED}{BW * AT}$$

Where for organics ($t_{event} \leq t^*$):

$$DA_{event} = 2 * FA * K_p * EPC_w * CF * \sqrt{\frac{6 * \tau_{event} * t_{event}}{\pi}}$$

Where for organics ($t_{event} > t^*$):

$$DA_{event} = FA * K_p * EPC_w * CF * \left[\left(\frac{t_{event}}{(1+B)}\right) + \left(2\tau_{event}\left[\frac{1+3B+3B^2}{(1+B)^2}\right]\right)\right]$$

Where for inorganics:

$$DA_{event} = K_p * EPC_w * CF * t_{event}$$

Dose = ADD or LADD (mg/kg-day)

DA_{event} = dose per event (mg/cm^2-event)

SSA_w = SSA available for contact with water (cm^2/event)

EV_w = event frequency (water) (events/day), assumed to be 1 per day unless otherwise noted

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight (kg)

t* = time to reach steady state (hours), equivalent to 2.4 x τ_{event}

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

FA = fraction absorbed (unitless)

K_p = permeability coefficient (centimeter/hour)

EPC_w = EPC in water (mg/L)

CF = conversion factor (1x10^{-3} liters per cubic centimeter)

T_{event} = lag time per event (hours/event)

B = permeability ratio (unitless)

t_{event} = event duration (hours/event)

3.1.3.1.5 Inhalation of Outdoor or Indoor Air

Exposure concentrations associated with the inhalation of vapors or particulates in outdoor or indoor air are calculated using USEPA (2009a) RAGS Part F methodology as follows:

$$\text{AEC or LAEC} = \frac{EPC_a * EF * ED * ET}{AT}$$

Where:

AEC or LAEC = average or lifetime exposure concentration in air (micrograms per cubic meter [$\mu g/m^3$])

EPC_a = EPC in outdoor or indoor air ($\mu g/m^3$)

EF = exposure frequency (days/year)

ED = exposure duration (years)

ET = exposure time (hours/day)

AT = averaging time (hours), for carcinogens is equal to 70 years * 365 days per year * 24 hours per day, and for noncarcinogens AT is equal to ED (in years) * 365 days per year * 24 hours per day

3.1.3.1.6 Ingestion of Homegrown Produce

Groundwater from the site may be used to irrigate locally grown crops, creating the potential for sulfolane to be taken up into plants that are then consumed by humans. In the few studies that have been conducted on the topic of uptake in plants, sulfolane has been demonstrated to be taken up into plants as the result of the constituent's high miscibility with water. Sulfolane is carried, along with water, through the roots, into the xylem and ultimately into the leaves of the plants. When water is lost through the leaves due to evapotranspiration, the sulfolane, due to its low volatility, tends to remain in the leaves where it may accumulate. Based on this information, it is assumed that if sulfolane is taken up by plants, it would predominantly be present in the leaves rather than in the roots or fruit.

This assumption is corroborated by the Final Results of the North Pole Garden Sampling Project (ADEC 2011b), which demonstrated that concentrations in roots were substantially lower than those in the stems and leaves. In the ADEC (2011b) study, which was led by ADHSS, 27 types of plant parts from multiple gardens irrigated with sulfolane-containing groundwater were collected from July to September 2010. Approximately one-half of the plant samples were reported as not detected, but 14 of the plant types tested were confirmed to contain sulfolane, primarily in the leaves and stems. Using data from the Final Results of the North Pole Garden Sampling Project (ADEC 2011b), the ADHSS evaluated the potential for risk to consumers of vegetables irrigated with sulfolane-containing water and concluded that sulfolane levels in the plants were low and not likely to cause any adverse health effects. However, because of the limited number of gardens sampled and the fact that the data were collected during only one growing season, the results of the investigation were considered preliminary and the exposure pathway was further evaluated in this assessment.

Following USEPA (2005) guidance, bioaccumulation of sulfolane in locally grown crops was evaluated using a biotransfer factor to estimate concentrations in plant tissues based on groundwater concentrations. There are no accepted values developed for sulfolane, but there is evidence to suggest that the uptake of sulfolane does not follow standard models based on partitioning coefficients (e.g., K_{ow}); therefore, an appropriate surrogate was not identified. Given the lack of constituent-specific information available in the literature, the ADEC has requested the use of a factor of 1. Use of this value assumes that the concentration of sulfolane in the edible portions of the plant tissues is equivalent to the concentration of sulfolane in groundwater.

After estimating the EPC, the doses of sulfolane associated with resident ingestion of homegrown fruits and vegetables were calculated using the following equation:

$$\text{Dose} = \frac{EPC_p * (IRP_{fr} + IRP_{vg}) * FI * EF * ED * CF}{BW * AT}$$

Where:

Dose = ADD (mg/kg-day)

EPC_p = EPC in produce (mg/kg) = EPC_w * BCF

Where:

EPC_w = EPC in water (mg/L)

BCF = water-to-produce bioconcentration factor (unitless)

IRP_{fr} = fruit ingestion rate (mg/day)

IRP_{vg} = vegetable ingestion rate (mg/day)

FI = fraction ingested (unitless)

EF = exposure frequency (days/year)

ED = exposure duration (years)

CF = conversion factor ($1x10^{-6}$ kg/mg)

BW = body weight (kg)

AT = for the noncarcinogen sulfolane is equal to ED * 365 days per year

The ADEC requested use of adult resident fruit and vegetable ingestion rates of 259,000 and 413,000 mg/day, respectively; child resident fruit and vegetable ingestion rates of 223,500 and 201,000 mg/day, respectively; and infant resident fruit and vegetable ingestion rates of 155,250 and 109,350 mg/day, respectively, based on 95th percentile *per capita* intakes presented in the USEPA (2011a) EFH Table 9-3. The intakes rates presented in the EFH were multiplied by receptor-specific BW (for example, adult fruit ingestion rate was calculated by 3.7 grams per kilogram per day * 70 kg * 1,000 milligrams per gram = 259,000 mg/day). These calculations translate into the assumption that infants will consume approximately 6 ounces of fruits and 4 ounces of vegetables a day; children will consume approximately 8 ounces of fruits and 7 ounces of vegetables a day; and adults will consume approximately 9 ounces of fruits and 15 ounces of vegetables a day. The risk assessment assumes that during their first year of life, infants will ingest approximately 228 pounds of homegrown fruits and vegetables. For children and adults, the assumption is approximately 342 and 548 pounds per year, respectively.

A fraction of 25 percent (i.e., an FI equal to 0.25) consumption of homegrown fruits and vegetables, for offsite residents is used in the exposure assessment. This represents a 3-month growing season.

3.1.3.1.7 Ingestion of Surface Water

The doses of sulfolane associated with ingestion of surface water while swimming were calculated as follows:

$$\text{Dose} = \frac{EPC_w * ET * EF * ED * CR_w}{BW * AT}$$

Where:

Dose = ADD (mg/kg-day)

EPC_w = EPC in water (mg/L)

ET = exposure time (hours per day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

CR_w = contact rate of surface water (liters/hour)

BW = body weight (kg)

AT = for the noncarcinogen sulfolane is equal to ED * 365 days per year

For the PPRTV Scenario, as shown in Table 3-12, the offsite adult and child recreational user surface-water ingestion rates of 0.071 and 0.12 liter/hour, respectively, were based on recommended upper percentile values for swimmers presented in the USEPA (2011a) EFH Table 3-5 representing the maximum ingestion rate for adults and the 97th percentile ingestion rate for children age 18 and under. Adult and child (1 to 6 years of age) recreational users were assumed to swim for 30 and 6 years, respectively, for 60 days per year for 1 hour per day.

3.1.3.2 Exposure Point Concentrations

Per ADEC (2010a) guidance, “the exposure point concentration is used to assess risk and should be estimated using a 95% UCL on the mean of the contaminant concentrations.” The EPC represents the average concentration of a COPC in an environmental medium that is potentially contacted by a receptor

during the exposure period (USEPA 1989). The USEPA (1989) also recommends the use of the 95% UCL as a conservative estimate of the EPC, because it represents the average concentration for which we have 95 percent confidence that the true mean concentration has not been exceeded. Unless there is site-specific evidence to the contrary, an individual receptor is assumed to be equally exposed to media within all portions of the EU during the time of the risk assessment (USEPA 2002c). For this HHRA ADEC has also requested evaluation of maximum COPC concentrations in groundwater as EPCs in the PPRTV Scenario. Note that the ADEC Draft Risk Assessment Procedures Manual was updated during preparation of this HHRA (ADEC 2011c). The updated manual includes guidance on the use of maximum groundwater concentrations for EPCs.

EPCs are estimated separately for each medium. Consistent with USEPA (2006b, 2007) guidance, surface soil, subsurface soil and groundwater EPCs were estimated using the 95% UCL of the mean for datasets with at least eight samples and at least five detected values. For this HHRA, a "dataset" was considered the aggregate of samples for one COPC, for one pathway, within a particular EU (onsite or offsite). Calculation of a 95% UCL depends on the distribution of the dataset and variability in the data. To assess statistical validity, data evaluation, distribution testing and 95% UCL calculations were performed using the USEPA's ProUCL version 4.1 (http://www.epa.gov/osp/hstl/tsc/software.htm) and according to the recommendations provided in the associated technical documentation (USEPA 2006, 2007, 2011b). Analytical data used for the HHRA are provided in Appendix A and ProUCL output files are included in Appendix B. For datasets with fewer than eight samples or fewer than five detected values, the EPC was the maximum detected concentration. Soil and groundwater datasets for most COPCs have more than eight samples each.

To combine data collected from monitoring wells and private residential wells, individual well means were calculated. The following methods were used to normalize the groundwater data in a manner that provides equal representation between wells with different numbers of observations:

- For a given well, if all samples were reported as non-detects, then the lowest detection limit associated with any sampling event at that well was used to represent the well.

- If a well had both detected concentrations and reported non-detects for a given COPC, then any non-detect was represented as one-half the detection limit associated with that sampling event for that COPC.

With the individual well means calculated as described above, ProUCL was used to estimate the 95% UCL of the mean of sulfolane across all wells in an EU (Figure 3-3). EU-1 represents approximate sulfolane concentrations in groundwater of $\geq$100 µg/L, EU-2 where detected sulfolane concentrations range from $\geq$25 to 99.9 µg/L, and EU-3 where sulfolane concentrations ranged from not detected above the laboratory reporting limit to 24.9 µg/L. Given the sizable area of each EU, some results included in the data analyses are different from others in each EU. For example, some non-detect results occur in EU-1 and EU-3. These

values are primarily attributable to groundwater samples collected from variable screen depths. It is reasonable to assume that groundwater extracted from a variety of screen lengths may be ingested by potential receptors that might use groundwater as drinking water. Therefore, these data points were included in the EPC calculations for each EU. Non-detect observations for the COPCs in soil and groundwater were addressed using the methods described above.

In addition, per ADEC (2010a) guidance for duplicate samples, the highest detected value from the primary and duplicate samples was used to represent that sample result. For any COPC, if the 95% UCL COPC of the mean concentration exceeded the maximum detected concentration, then the maximum detected concentration was the EPC. Summary statistics for the COPCs are presented in the risk characterization, including detection frequency, number of samples, minimum and maximum detected concentrations, and calculated 95% UCL concentrations.

EPCs were estimated separately for each medium. Tables 3-3 through 3-10 present area-wide summary statistics and EPCs for COPCs as follows:

- Surface soil (0 to 2 feet bgs; see Table 3-3 for 95% UCL COPC concentrations)
- Subsurface soil (0 to 15 feet bgs; see Table 3-4a for maximum COPC concentrations and Table 3-4b for 95% UCL COPC concentrations)
- Onsite groundwater (see Table 3-5a for maximum COPC concentrations and Table 3-5b for 95% UCL COPC concentrations)
- Offsite groundwater in all wells (see Table 3-6 for maximum sulfolane concentration)
- Offsite groundwater in EU-1 (see Table 3-7 for 95% UCL sulfolane concentration)
- Offsite groundwater in EU-2 (see Table 3-8a for maximum sulfolane concentration and Table 3-8b for 95% UCL sulfolane concentration)
- Offsite groundwater in EU-3 (see Table 3-9a for maximum sulfolane concentration and Table 3-9b for 95% UCL sulfolane concentration)
- Offsite surface water (see Table 3-10 for maximum sulfolane concentration estimated from pore water).

Soil, groundwater, outdoor air, indoor air, homegrown produce and surface-water EPCs are further discussed below.

3.1.3.2.1 Soil Exposure Point Concentrations

Onsite receptors may potentially contact surface soil or a combination of surface and subsurface soil. According to ADEC guidance 18 AAC 75.340(j)(2), "human exposure from ingestion, direct contact or inhalation of a volatile substance must be attained in the surface soil and the subsurface soil to a depth of at least 15 feet, unless an institutional control or site conditions prevent human exposure to the subsurface" (ADEC 2008c). Currently and in the future, FHRA will have institutional controls in place (i.e., permits) that provide worker protection (i.e., appropriate personal protective equipment) in the event of planned excavation of onsite soil. For this HHRA, two soil EPCs are calculated for each COPC. Surface soil is considered to occur from 0 to 2 feet bgs (Table 3-3) and subsurface soil is considered to occur from 0 to 15 feet bgs (Tables 3-4a and 3-4b). EPCs for soil were calculated using the 95% UCL on the mean of the dataset for surface soil exposures, or the maximum detected COPC concentrations for surface and subsurface soil exposures (relevant to potential onsite construction/trench workers).

3.1.3.2.2 Surface Soil Exposure Point Concentrations

For this HHRA, it is presumed that onsite commercial/industrial workers may potentially contact surface soil onsite that is not covered with pavement or vegetation. Therefore, surface soil EPCs were calculated and used to evaluate potential exposure by onsite commercial/industrial workers, using analytical data from the surface soil dataset in uncovered portions of the site (i.e., soil samples collected from ground surface to 2 feet bgs). The 95% UCL of the mean concentrations of COPCs in surface soil collected from 0 to 2 feet bgs were used to evaluate:

- Direct-contact exposure pathways to onsite outdoor commercial/industrial workers
- Potential inhalation of fugitive windborne dust from onsite surface soil by onsite outdoor commercial/ industrial workers, offsite residents and offsite outdoor commercial/industrial workers.

3.1.3.2.3 Surface and Subsurface Soil Exposure Point Concentrations

The 95% UCL of the mean concentrations of surface soil collected from 0 to 2 feet bgs were used to evaluate direct-contact exposure pathways to onsite outdoor commercial/industrial workers, and potential inhalation of fugitive windborne dust from onsite soil by onsite and offsite outdoor commercial/industrial workers. The onsite construction/trench worker may be directly exposed to surface and subsurface soil during excavation activities. Therefore, EPCs for evaluating exposure by the onsite construction/trench worker were generated using analytical data from the combined surface and subsurface soil dataset (i.e., soil samples collected from ground surface to as deep as 15 feet bgs). The maximum detected concentrations in the combined surface and subsurface soil sample dataset were used to estimate

surface and subsurface soil EPCs for direct-contact pathways for the onsite construction/trench worker because that exposure may be localized rather than averaged over the entire site. In addition, in accordance with ADEC guidance (2010a), surface and subsurface soil EPCs based on the 95% UCLs were also used to evaluate potential exposures by the construction/trench worker.

3.1.3.2.4 Groundwater Exposure Point Concentrations

For COPCs in groundwater, COPC EPCs were distinguished for both on- and offsite potential exposures as described in the following sections.

3.1.3.2.4.1 Onsite Groundwater Exposure Point Concentrations

Groundwater EPCs were used to estimate direct-contact exposure (i.e., dermal contact) by the onsite outdoor worker and incidental ingestion and dermal contact by onsite construction/trench workers during excavation activities. Groundwater COPC EPCs were estimated using the last 2 years of data (i.e., 2009 to 2011) collected from onsite groundwater monitoring wells. In addition to evaluating the potential exposures to COPCs in groundwater over an EU using 95% UCL concentrations, the ADEC also requested that groundwater EPCs be calculated using the maximum detected concentration during the last 2 years of groundwater monitoring (see Tables 3-5a and 3-5b).

3.1.3.2.4.2 Offsite Groundwater Exposure Point Concentrations

Offsite sulfolane groundwater EPCs were used to estimate direct-contact exposure (i.e., incidental ingestion) by offsite construction/trench workers during excavation activities and to estimate direct-contact exposure (i.e., ingestion) by offsite residents and commercial/industrial receptors. In addition to evaluating the potential exposures to sulfolane in groundwater using a 95% UCL concentration for each of the EUs depicted on Figure 3-3, the ADEC also requested risk calculations using the maximum detected sulfolane concentration during the last 2 years of groundwater monitoring (i.e., 2009 to 2011), applied to the entire offsite area. EPCs were derived for each offsite EU identified on Figure 3-3 including:

- All offsite wells (Table 3-6), evaluated using the maximum offsite concentration as the EPC
- EU-1 (Table 3-7), evaluated using the 95% UCL concentration in offsite wells in EU-1 (the maximum concentration located in EU-1 is the same as the off-site maximum concentration, as shown in Table 3-6)
- EU-2 (Table 3-8a for maximum concentrations and Table 3-8b for 95% UCL concentrations)
- EU-3 (Table 3-9a for maximum concentrations and Table 3-9b for 95% UCL concentrations).

In summary, the maximum detected concentrations of sulfolane in offsite groundwater from EU-1, EU-2 and EU-3 were used to estimate risks and hazards for relevant receptors for the PPRTV Scenario. In addition, for each EU, EPCs based on the 95% UCL were also used to estimate risks and hazards for relevant receptors at each of the offsite groundwater offsite EUs (EU-1, EU-2 and EU-3), per USEPA (1989) guidance, professional judgment, and the RAWP (ARCADIS 2011).

3.1.3.2.5 Outdoor Air Exposure Point Concentrations

In accordance with the USEPA (1989), exposure to constituents in outdoor air was evaluated as exposure to fugitive dust emissions (for non-VOCs, from soil only) or volatile emissions (for VOCs, from soil or groundwater). The USEPA (2002b) recommendations for media transfer factors to evaluate these exposures are described below.

3.1.3.2.5.1 Estimating Outdoor Air Exposure Point Concentrations from Soil Concentrations

A particulate emission factor (PEF) for non-volatile COPCs was used to estimate EPCs in outdoor air from soil. The industrial PEF (1.36×10^9 cubic meters per kilogram [m^3/kg]) obtained from the Supplemental Guidance for Developing Soil Screening Levels for Contaminated Sites (USEPA 2002b) was used to estimate outdoor air EPCs of non-volatile COPCs for onsite outdoor commercial/industrial workers and construction/trench workers potentially exposed to particulate emissions from soil.

A volatilization factor (VF) for VOCs was used to estimate EPCs of volatile COPCs in outdoor air from soil (VF_{soil}). Outdoor air EPCs were estimated for the onsite outdoor commercial/industrial worker and onsite construction/trench worker using the EPC for the combined surface and subsurface soil dataset. Constituent-specific VFs_{soil} were obtained from the USEPA (2011c) RSL spreadsheets, where they exist, to estimate outdoor air EPCs of volatile COPCs for onsite outdoor commercial/industrial workers and construction/trench workers potentially exposed to volatile COPCs emanating from surface and subsurface soil. For volatile COPCs not listed in the USEPA's RSL table, VFs were derived according to USEPA guidance (USEPA 2002b). Table 3-11 presents the VFs_{soil} that were used to calculate VFs_{soil} if they were not available on the RSL spreadsheets.

The following equation was used to calculate outdoor air EPCs from soil EPCs using either a PEF or VF_{soil}:

$$EPC_a = \frac{EPC_s}{PEF \text{ or } VF_{soil}}$$

Where:

EPC_a = EPC in air (mg/m^3)

EPC_s = EPC in soil (mg/kg)

PEF = particulate emission factor (m^3/kg)

VF_{soil} = volatilization factor (soil) (m^3/kg)

3.1.3.2.5.2 Estimating Outdoor Air Exposure Point Concentrations from Groundwater Concentrations

Construction workers (i.e., trench workers) may also be exposed to VOCs released from shallow groundwater that may pool in a trench and volatilize to trench air. Groundwater occurs as shallow as 8 feet bgs in portions of the site. To estimate the potential concentrations of COPCs that could volatilize from groundwater to trench air, volatilization factors (VF_{gw}) obtained from the Virginia Department of Environmental Quality (2012) were used to estimate trench air EPCs from groundwater. The trench air EPCs were used to evaluate potential exposures by on and offsite construction/trench workers potentially exposed to volatile COPCs emanating directly from shallow groundwater in an excavation trench. The equation for using VF_{gw} to calculate trench air EPCs from groundwater EPCs is as follows:

$$EPC_a = EPC_{gw} * VF_{gw}$$

Where:

EPC_a = EPC in trench air (mg/m^3)

EPC_{gw} = EPC in groundwater (mg/L) (as 95% UCL and as maximum EPC; see Section 3.1.3.2.4 for discussion about on and offsite groundwater EPCs)

VF_{gw} = volatilization factor (groundwater) (liter per cubic meter)

For onsite exposures, the trench air EPCs are presented in Table 3-5a (maximum EPC) and Table 3-5b (95% UCL EPC).

As discussed in Section 3.1.1, onsite construction/trench workers may potentially be exposed to vapors emanating from soil during trench excavation. Therefore, potential exposures to volatile EPCs in trench air from both soil and shallow groundwater sources, as well as COPCs as fugitive dust from soil were estimated for onsite construction/trench workers. For offsite construction/trench workers, sulfolane in trench air from offsite groundwater is the only potential exposure onsite.

3.1.3.2.6 Indoor Air Exposure Point Concentrations

The Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (USEPA 2002a), Vapor Intrusion Pathway: A Practical Guide (ITRC 2007a) and Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios (ITRC 2007b) were used to assess vapor intrusion. The J&E model was used to estimate indoor air concentrations resulting from intrusion of vapors from sub-slab soil gas into onsite buildings. The J&E model is a one-dimensional, screening-level model used to evaluate subsurface vapor intrusion into buildings. It incorporates both convective and diffusive mechanisms to estimate the transport of constituent vapors emanating from soil gas into indoor spaces located directly above the source (J&E 1991, USEPA 2004b). When estimating the concentration of COPC vapors in indoor air, the J&E model assumes the following:

- Constant, infinite source of constituents (e.g., in groundwater or soil gas)
- Steady-state diffusion through the unsaturated zone
- Convective and diffusive transport through the basement floor or slab
- Complete mixing within the building, estimated using an air exchange rate.

Due to the uncertainties associated with partitioning from soil to soil gas, ITRC (2007b) does not recommend using soil data as a source of COPCs to evaluate potential vapor intrusion. Therefore, source concentrations were estimated using the groundwater data as discussed in Section 2.6.2. Source concentrations for the model consisted of the groundwater EPCs based on maximum detected COPC concentrations in groundwater as well as the 95% UCL of the mean groundwater concentrations (see Section 3.1.3.2.4). Site-specific parameters, such as soil type and average soil temperature, were used in the J&E model where available. The top 3 to 5 feet of soil was assumed to be sand. Geotechnical data show that this depth interval is silty sand. An average soil temperature of 5 °C was used. The remaining parameter values, including constituent-specific parameter values, were estimated using the default values provided by the USEPA (2004b) in the User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings and the associated model spreadsheets. Appendix C presents the results of the USEPA's J&E-based model to predict indoor air COPC concentrations from COPC concentrations in onsite groundwater. For onsite exposures, the indoor air EPCs are presented in Table 3-5a (maximum EPC) and Table 3-5b (95% UCL EPC).

3.1.3.2.7 Homegrown Produce Exposure Point Concentrations

Residents who consume homegrown produce that has been irrigated with offsite groundwater were evaluated. Homegrown produce EPCs were calculated using bioconcentration factors (BCFs) applied to offsite groundwater EPCs (Tables 3-6 through 3-9b). The Final Results of the North Pole Garden Sampling Project (ADEC 2011b) showed that sulfolane was taken up into garden plants at concentrations below adult risk-based screening criterion developed by the ADHSS. However, a BCF equal to 1 was used to

predict uptake of sulfolane into both aboveground and belowground vegetables (as described in Section 3.1.3.1.6).

3.1.3.2.8 Surface-Water Exposure Point Concentrations

Recreational users who ingest surface water that has migrated from groundwater beneath the site were evaluated. The maximum detected concentration of sulfolane collected during the 2012 field season from adjacent to a frozen surface-water body was assumed to represent groundwater that has migrated offsite to downgradient water bodies. Summary statistics and the surface-water EPC are presented in Table 3-10.

3.1.3.3 Exposure Parameters

Exposure parameter values that were identified for each receptor at the site for the PPRTV scenario are provided in Table 3-12. The exposure parameters were based primarily on those provided in ADEC (2010a) and USEPA (1989, 1991, 1997a and 2004a) as well as other sources, as noted. These exposure parameters meet or exceed the USEPA (1989) approach for estimating reasonable maximum exposure (RME), which is the maximum exposure that is reasonably expected to occur in a population. Its intent is to estimate a health-protective exposure case (i.e., well above the average case) that is still within the range of possible exposures (USEPA 1989). Mathematically, the RME estimate for each exposure pathway combines upper percentile values and assumptions with selected average values and assumptions. The upper percentile assumptions tend to maximize estimates of exposure, such as choosing a value near the high end of the concentration or intake range. Therefore, the RME estimates tend to be at the high end of the exposure range, generally greater than the 90^{th} percentile of the population.

3.1.3.4 Assessment of Potential Lead Exposures

The potential hazard associated with lead exposure was evaluated by comparing the predicted blood-lead concentrations to the Centers for Disease Control and Prevention (CDC) blood-lead threshold concentration. The threshold lead concentration is 10 micrograms per deciliter (µg/dL) of whole blood based on potentially adverse neurological effects in children (CDC 2011). A blood-lead concentration of less than 10 µg/dL was deemed acceptable. The USEPA's (2009b) Adult Lead Model (ALM) model, which estimates the blood-lead levels of workers and the fetus of a pregnant worker, was used to evaluate the potential onsite exposure to lead in groundwater for the receptors evaluated.

3.2 Toxicity Assessment

The toxicity assessment identified toxicity values that relate exposure (dose) to potential risk or hazard for each COPC. Toxicity values derived from dose-response data were combined with estimates of exposure to characterize potential noncarcinogenic hazard and carcinogenic risk (see Section 3.3.2). Toxicity profiles were provided for risk/hazard drivers and sulfolane. Selection of toxicity values followed the hierarchies described below.

3.2.1 Noncarcinogenic Toxicity Values

Chronic and subchronic reference doses (RfDs) were used to evaluate potential adverse effects from ingestion, dermal and inhalation (dust) exposures to noncarcinogenic COPCs. Chronic RfDs, which correspond to 7 or more years of exposure, are specifically developed to be protective of long-term exposures to a constituent with a considerable health-protective margin of safety, which is usually over 1000-fold. The USEPA (1989) defines the chronic RfD as "a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime."

The following sources were used to identify chronic toxicological reference values:

- USEPA (2012a) IRIS.
- USEPA PPRTVs, derived by the USEPA's Superfund Health Risk Technical Support Center for the USEPA Superfund program. Current values were obtained directly from the USEPA.
- California Environmental Protection Agency (CalEPA) reference exposure levels from the California Office of Health Hazard Environmental Assessment (OEHHA).
- ATSDR Minimal Risk Levels (MRLs) (ATSDR 2012) Chronic MRLs were used to evaluate chronic exposure.
- USEPA (1997b) Health Effects Assessment Summary Tables (HEAST).

The USEPA (1989) defines exposures lasting between 2 weeks and 7 years as subchronic exposures. As a result, the short-duration and intermittent nature of construction/trench worker and infant exposures required consideration of subchronic toxicity values (subchronic RfDs) to estimate the potential for effects. Subchronic RfDs are developed to be protective of subchronic exposures to constituents with a conservative measure of safety (USEPA 1989). Subchronic RfDs for ingestion (oral) and inhalation (dust and vapor) exposure were identified from the following sources, in the following order of priority:

- USEPA PPRTVs. Current values were obtained directly from the USEPA.
- ATSDR MRLs (ATSDR 2012). Intermediate MRLs were used to evaluate subchronic exposure.
- USEPA (1997b) HEAST.

For the PPRTV Scenario, in addition to chronic RfDs, subchronic RfDs, if available, were used to evaluate potential exposures to onsite construction/trench workers and offsite infants. If subchronic RfDs were unavailable, then only chronic RfDs were used. For the PPRTV Scenario, chronic RfDs were used for offsite children.

Current USEPA guidance recommends calculating a dermal RfD by multiplying the oral RfD by the percent oral absorption efficiency (ABSGI). This recommendation requires one of the following:

- A critical study upon which the toxicity value is based employed an administered dose (e.g., delivery in diet or by gavage) in its design.

- A scientifically defensible database exists that demonstrates that the gastrointestinal absorption of the constituent in question from a medium (e.g., water, feed) similar to the one employed in the critical study is significantly less than 100 percent (e.g., less than 50 percent).

Values for ABSGI were obtained from RAGS (USEPA 2004a). Chronic and subchronic RfDs are presented in Table 3-13.

3.2.2 Carcinogenic Toxicity Values

Oral cancer slope factors (CSFs) and inhalation unit risk (IUR) factors were used to evaluate potential carcinogenic effects from ingestion, dermal and inhalation exposures to COPCs. CSFs quantitatively describe the relationship between dose and response. A CSF represents the 95% UCL of the slope of the dose-response curve and is derived using a low-dose extrapolation procedure that assumes linearity at low doses. By applying a CSF to a particular exposure level of a potential carcinogen, the upper bound lifetime probability of an individual developing cancer related to that exposure can be estimated.

CSFs have been developed for the oral and inhalation (dust particulates) exposure routes; IURs have been developed for the inhalation exposure route. CSFs for oral and IURs for inhalation exposures were identified from the following sources, in the following descending order of priority:

- USEPA (2012a) IRIS.
- USEPA PPRTVs. Current values were obtained directly from the USEPA.
- CalEPA (2012) OEHHA Toxicity Criteria Database.
- USEPA (1997b) HEAST.

As is the case for noncarcinogenic toxicity, the USEPA has not developed dermal CSFs for use in risk assessment. Dermal CSFs were calculated in a manner similar to that of noncarcinogenic RfDs for dermal exposure by dividing the oral CSFs by the ABSGI AF (USEPA 2004a). CSFs are presented in Table 3-13.

3.2.3 Sulfolane Toxicity Values

Toxicity values for sulfolane are not presented in IRIS (USEPA 2012a). However, a PPRTV chronic oral RfD of 0.001 mg/kg-day and a PPRTV subchronic oral RfD of 0.01 mg/kg-day have been prepared for sulfolane (USEPA 2012b).

The PPRTV Scenario risk assessment presents estimated hazards for potential sulfolane exposures using the USEPA (2012b) PPRTV oral RfDs for sulfolane

3.2.4 Toxicity Equivalence Factors for Polynuclear Aromatic Hydrocarbons

As shown in Tables 3-2a and 3-2b, some carcinogenic PAHs have been identified as COPCs in soil. Following ADEC (2010a) guidance, toxicity equivalence factors (TEFs) were used to assess risks to carcinogenic PAHs, including benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene and indeno(1,2,3-c,d)pyrene). TEFs were applied to EPCs of all carcinogenic PAHs in surface and subsurface soil to equivalent concentrations of benzo(a)pyrene (USEPA 2011c) and total risk was derived for the carcinogenic PAH COPCs. The assessment of potential exposures to other PAHs also included PAHs identified as COPCs in soil based on analytical data collected during the 2011 field season.

3.3 Risk Characterization – Provisional Peer Reviewed Toxicity Value Scenario

This section presents the PPRTV Scenario and provides estimated ELCRs and hazard indices (HIs) for potentially complete and significant exposure pathways identified in Section 3.1.1.4 for on- or offsite potential receptors, based on the USEPA (2012a) PPRTV toxicity criteria for sulfolane and the exposure parameters presented in Table 3-12.

3.3.1 Risk Characterization – PPRTV Scenario

The risk characterization integrates results of the data evaluation, exposure assessment and toxicity assessment to evaluate potential risks associated with exposure to site COPCs. The basis for the risk characterization is the quantitative evaluation of potential exposure by potential receptors to COPCs, which consists of estimating carcinogenic risk and noncarcinogenic hazard. This quantitative evaluation of risk and hazard generally provides a health-protective representation of the upper end (potentially highest

exposures) for a receptor. The quantitative methods used to calculate noncarcinogenic hazard and carcinogenic risk are presented below. Consistent with USEPA (1989) guidance, the potential for carcinogenic and noncarcinogenic risks were evaluated separately.

3.3.1.1 Carcinogenic Risk

For potential carcinogens, risk was estimated as the incremental probability of an individual developing cancer during a lifetime as a result of RME to a potential carcinogen and was calculated as follows:

$$ELCR = LADDi \times CSFi$$

Where:

ELCR = excess lifetime cancer risk (unitless)

LADDi = lifetime average daily dose for the *i* th constituent (mg/kg BW-day)

CSFi = cancer slope factor for the *i* th constituent $(mg/kg\ BW\text{-}day)^{-1}$.

The CSF converts intake averaged over a lifetime of exposure to the incremental lifetime risk of an individual developing cancer. This linear equation is only valid at low risk levels (i.e., below estimated risks of one in 100) and is an upper-bound estimate based on the 95% UCL of the slope of the dose-response curve. Therefore, the actual risk will be lower than the predicted risk. Potential risk was assumed to be additive, and risks from different possible and probable carcinogens and pathways were summed to evaluate the overall risk. Pathway-specific risks were calculated as the sum of risks from potential carcinogenic COPCs within each exposure pathway, and the total ELCR for each receptor was calculated by summing the risk estimates for the exposure pathways evaluated.

For inhalation of COPCs, the following equation from USEPA (2009a) RAGS Part F was used to assess ELCRs:

$$ELCR = LAEC * IUR$$

Where:

ELCR = excess lifetime cancer risk (unitless)

LAEC = lifetime average exposure concentration ($\mu g/m^3$)

IUR = inhalation unit risk $(\mu g/m^3)^{-1}$

Scientific notation was used to express potential carcinogenic risks. For example, a value of $1x10^{-6}$ is equal to one in 1 million (or 0.000001). For individual constituents, the ADEC (2010a) compares risk estimates to an acceptable cumulative ELCR of 1×10^{-5}. The acceptable cancer risk (or range of risks) is the incremental risk attributed to the estimated upper-bound exposure (i.e., RME) to COPCs at the site. This acceptable risk is, by definition, independent of risks associated with non-site-related constituent exposures and other background cancer risks (USEPA 1989).) It is standard USEPA and ADEC practice, however, to assess risks and hazards first with background constituents included and then discuss the risks in the absence of the background impacts to inform the decision makers about the risks of site-related constituents.

3.3.1.2 Noncarcinogenic Hazard

The HQ approach was used to characterize the overall potential for noncarcinogenic effects associated with exposure to multiple constituents. This approach assumes that chronic and subchronic exposures to multiple constituents are additive. For direct contact and inhalation of particulates exposures, the HQ was calculated as follows:

$$HQ = ADD / RfD$$

Where:

HQ = hazard quotient (unitless)

ADD = average daily dose (mg/kg-day)

RfD = reference dose $(mg/kg\text{-}day)^{-1}$

For inhalation of volatile COPCs, the following equation from USEPA (2009a) RAGS Part F was used to assess noncancer hazards:

$$HQ = AEC / RfC$$

Where:

HQ = hazard quotient (unitless)

AEC = average exposure concentration (micrograms per cubic centimeter [$\mu g/cm^3$])

RfC = inhalation reference concentration $(\mu g/cm^3)^{-1}$

The HQ represents the comparison of exposure (dose) over a specified period of time to an RfD for a similar time period. The estimates of exposure (dose) were calculated based on chronic or subchronic exposures. If the HQ exceeds a value of 1, there is a possibility of adverse health effects. The magnitude of the HQ is not a mathematical prediction of the severity or incidence of the effects, but rather indicates that effects may occur. The likelihood of effects occurring at levels above an HQ=1 is based on the nature of the effects used to set the RfD and the magnitude of the composite uncertainty factor used in the RfD derivation. The constituent HQs were summed to calculate an HI for a pathway or site, and the USEPA (1989) recommends that the total HI for the constituents and pathways assessed not exceed a value of 1. An HI of less than 1 indicates that adverse health effects are not likely to occur from exposure to assessed constituents. HQs or HIs of greater than 1 do not indicate that significant risks are present, but rather that additional evaluation may be required to better define the level of risk.

According to the USEPA (1989), noncarcinogenic effects should be evaluated based on target organ(s) or toxicity endpoints. The USEPA believes that the assumption of dose additivity is one of the major limitations of the HI approach because it may overestimate the potential for health effects that most likely will not occur if the COPCs affect different organs or act by different mechanisms of action. The USEPA counters the potential for overestimation by specifying segregation of COPCs by effect and mechanism of action, and derivation of separate HIs for each group (USEPA 1989). If the total HI exceeds a value of 1, the specific substances will be evaluated so that only substances that affect similar target organs or exhibit a similar mode of action (i.e., similar effects in the same target organs via the same mechanism) are summed. Quantitative estimates of carcinogenic risk and noncarcinogenic hazard were presented for each receptor.

3.3.1.3 Risk Characterization of Petroleum Hydrocarbon Compounds

In accordance with ADEC (2008b) Cumulative Risk Guidance, individual risks from exposure to GRO, DRO and RRO were calculated using RfDs provided by ADEC (2010a). However, these risk calculations were not included in cumulative risk estimates. Consistent with ADEC (2008b) Cumulative Risk Guidance, cumulative risks for each receptor were estimated using indicator constituents, as discussed below.

In general, quantitative risk calculated from individual petroleum constituents is considered adequate to account for risk in cumulative risk calculations from petroleum mixtures (ADEC 2008b). The key constituents of petroleum products associated with risk (e.g., PAHs, BTEX, methyl tertiary butyl ether) are included in the quantitative cumulative risk calculations and should adequately describe human health risk from exposure to site media.

3.3.2 Estimated Risks and Hazards for Provisional Peer Reviewed Toxicity Value Scenario

For each total estimated ELCR and HI, the primary exposure pathway and contributing COPC(s) are indicated, as appropriate. This section presents ELCRs and hazards for potential onsite receptors (Section 3.3.2.1) and potential offsite receptors (Section 3.3.2.2). For each potential receptor, ELCRs and/or HIs are summarized based on possible exposure to maximum and/or 95% UCL-based EPC COPC concentrations. Appendices D and E present complete risk calculations for ELCRs and HIs based on maximum and 95% UCL COPC concentrations, respectively.

Summaries of the cumulative ELCRs and estimated HIs for the receptors evaluated under the PPRTV Scenario are presented in the following tables:

- Tables 3-14 and 3-15 present the ELCR and HI summaries for on and offsite receptors using the maximum detected on and offsite values and the 95% UCL on and offsite values, respectively.
- Tables 3-14, 3-16a and 3-17a present ELCR and HI summaries for potential on and offsite receptors based on maximum COPC concentrations for all wells in each EU (including EU-1 because the maximum for all offsite wells is located in this EU).
- Table 3-15 presents ELCR and HI summaries for potential on and offsite receptors at EU-1 based on 95% UCL EPCs.
- Table 3-16a presents ELCR and HI summaries for offsite receptors based on maximum COPC concentrations at EU-2 wells.
- Table 3-17a presents ELCR and HI summaries for offsite receptors based on maximum COPC concentrations at EU-3 wells.

The PPRTV scenario risk assessments are presented in Appendix D (maximum concentrations) and Appendix E (95% UCL EPCs). Appendix H provides toxicity profiles for the primary risk and hazard drivers, including: arsenic, benzene, naphthalene, sulfolane, 1,3,5-trimethylbenzene and xylenes.

The total estimated ELCRs presented in Tables 3-14 through 3-17b include arsenic as a soil COPC (arsenic was excluded as a COPC in groundwater). Based on an evaluation of arsenic in soil samples at the site, the presence of arsenic is due to background concentrations. Detected concentrations of arsenic in soil samples collected at the site are evaluated in the 2012 Revised Site Characterization Report (Barr 2012). This evaluation compared site arsenic concentrations to background studies collected in Alaska and evaluated the spatial distribution of arsenic with respect to site operations and other COPCs. The

results of the evaluation concluded that the presence of arsenic in soil does not appear to be associated with refinery operations and is likely a result of background concentrations.

3.3.2.1 Estimated Risks and Hazards for Potential Onsite Receptors

Potential onsite receptors evaluated include current and future indoor and outdoor commercial workers, construction/trench workers and adult visitors. The USEPA (2012b) chronic PPRTV oral RfD was used to evaluate potential sulfolane exposures. The maximum onsite concentration of sulfolane in groundwater detected above the laboratory reporting limit between 2009 and 2011 is 10.4 mg/L. Estimated risks and hazards for the onsite receptors using maximum detected concentrations and 95% UCLs as EPCs are summarized in Table 3-14 and Table 3-15, respectively.

3.3.2.1.1 Onsite Indoor Commercial/Industrial Workers

Table D-1 (Appendix D) presents the estimated ELCRs and HIs for indoor commercial/industrial workers, based on exposures to maximum detected COPC concentrations in groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors (see Table 3-14). The total estimated ELCR is 1×10^{-5} and the total estimated HI is 0.2.

Table E-1 (Appendix E) presents the estimated ELCRs and HIs for indoor commercial/industrial workers, based on exposures to 95% UCLs of detected COPC concentrations in groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors (see Table 3-15). The total estimated ELCR is 1×10^{-6} and the total estimated HI is 0.02.

3.3.2.1.2 Onsite Outdoor Commercial/Industrial Workers

Table D-2 (Appendix D) presents the estimated ELCRs and HIs for outdoor commercial/industrial workers, assuming potential exposure to 95% UCLs of COPC concentrations in surface soil. Table D-2 also shows estimated ELCRs and HIs based on direct-contact exposures, including ingestion of, dermal contact with and inhalation of dust particles from surface soil. The total estimated ELCR is 5×10^{-6} and the total estimated HI is 0.05 (see Table 3-14). Soil ingestion contributes most to the total estimated ELCR and HIs. Arsenic is the primary risk and hazard driver. Excluding the estimated arsenic ELCR and HI, which are likely due to background, the total estimated ELCR is 2×10^{-7} and the total estimated HI is 0.03 (see Table D-2).

3.3.2.1.3 Onsite Construction/Trench Workers

The USEPA (2012b) PPRTV subchronic oral RfD for sulfolane was used to estimate potential construction/ trench worker hazards. Table 3-14 and Table D-3a (Appendix D) present the estimated ELCRs and HIs for construction/trench workers based on potential exposures to maximum COPC concentrations in surface and

subsurface soil, assuming direct-contact exposures including ingestion, dermal contact and inhalation of dust particles. The total estimated ELCR associated with potential exposure to COPCs in soil is 1×10^{-6} and the total estimated HI is 0.3. The soil ingestion pathway contributes most to the total soil-related estimated ELCR and HI. Excluding the estimated arsenic ELCR, which is likely based on background, the total estimated ELCR is 3×10^{-7} and the total estimated HI is 0.3.

Table 3-14 and Table D-3b (Appendix D) present ELCRs and HIs based on incidental ingestion of and dermal contact with groundwater in an onsite excavation trench, and inhalation of VOCs within trench air from groundwater based on maximum COPC concentrations in groundwater. The total estimated ELCR is 3×10^{-4} and the total estimated HI is 49. Inhalation of VOCs in the trench air is the exposure pathway that contributes most to the cumulative ELCR and HIs. Benzene, naphthalene and ethylbenzene (as estimated in trench air from groundwater) are the primary risk drivers for the total ELCR. Benzene, naphthalene, xylenes and 1,3,5-trimethylbenzene are the risk drivers for the HI.

Table 3-15 and Table E-3a (Appendix E) present the estimated ELCRs and HIs for construction/trench workers based on 95% UCL COPC concentrations and direct-contact exposures including ingestion of, dermal contact with and inhalation of dust particles in surface and subsurface soil. The total soil-related estimated ELCR is 3×10^{-7} and the total soil-related estimated HI is 0.06. Soil ingestion contributes most to the total estimated ELCR and HIs. Excluding the estimated arsenic ELCR and HI, which are likely based on background, the total estimated ELCR is 2×10^{-8} and the total estimated HI is 0.05.

Table 3-15 and Table E-3b (Appendix E) present ELCRs and HIs based on incidental ingestion of and dermal contact with groundwater in an onsite excavation trench and inhalation of VOCs within trench air from groundwater based on 95% UCL COPC concentrations. The total estimated ELCR is 3×10^{-5} and the total estimated HI is 9. Inhalation of VOCs in the trench air contributes most to ELCR and HIs. Benzene is the primary risk driver for ELCRs and benzene and naphthalene are the primary risk drivers for HIs.

3.3.2.1.4 Onsite Adult Visitors

Table 3-14 and Table D-4 (Appendix D) present the estimated ELCRs and HIs for adult visitors based on maximum COPC concentrations in onsite groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors. The total estimated ELCR is 2×10^{-7} and the total estimated HI is 0.002.

Table 3-15 and Table E-4 (Appendix E) present the estimated ELCRs and HIs for adult visitors based on 95% UCL COPC concentrations in onsite groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors. The total estimated ELCR is 1×10^{-8} and the total estimated HI is 0.0004.

3.3.2.2 Estimated Risks and Hazards for Potential Offsite Receptors

Potential offsite receptors evaluated include current and future residents; adults (chronic exposures), children (chronic exposures) and infants (subchronic exposures); indoor and outdoor commercial workers (chronic exposures); and construction/trench workers (subchronic exposures). The estimated risks and hazards for offsite receptors using maximum detected concentrations and 95% UCLs as EPCs are summarized in Table 3-14 and Table 3-15 , respectively.

3.3.2.2.1 Offsite Adult, Child and Infant Residents

Table 3-14 and Tables D-5a and D-6a (Appendix D) present the estimated ELCRs and HIs for offsite adult and child residents, assuming potential exposure to 95% UCL COPC concentrations in ambient air from onsite surface soil (based on 95% UCL concentrations) using the USEPA (2012b) chronic PPRTV oral RfD for sulfolane. The total estimated ELCRs for adult and child residents are 4×10^{-8} and 9×10^{-9}, respectively, and the total estimated HIs are both 0.001. Excluding arsenic in soil and the estimated arsenic ELCRs and HIs, which is likely due to background, the total estimated ELCRs for adult and child residents are 4×10^{-8} and 8×10^{-9}, respectively, and the total estimated HIs are both 0.0009 (see Table D-5a [Appendix D] for adult resident and Table D-6a for child resident). Table D-7a presents the estimated ELCR and HI for offsite infant residents, assuming potential exposure to 95% UCL COPC concentrations in ambient air from onsite surface soil using the USEPA (2012b) subchronic PPRTV oral RfD for sulfolane. The total estimated ELCR for infant residents is 1×10^{-9} and the total estimated HI is 0.0007. Excluding the estimated arsenic ELCR and HI, which is likely due to background, the total estimated ELCR for infant residents is 1×10^{-9} and the total estimated HI is 0.0005.

Table 3-14 and Tables D-5b, D-6b and D-7b (Appendix D) show HIs based on ingestion of the maximum detected concentration of sulfolane in groundwater (i.e., tapwater), applied across the entire offsite area (which also includes EU-1 because the maximum value occurs in this EU), for adults (chronic exposures; Table D-5b), children (chronic exposures; Table D-6b) and infants (subchronic exposures; Table D-7b), respectively. Tables D-5c, D-6c and D-7c present the HIs associated with ingestion of homegrown produce irrigated with sulfolane-impacted groundwater (maximum detected concentration) for adults (chronic exposures; Table D-5c), children (chronic exposures; Table D-6c) and infants (subchronic exposures; Table D-7c), respectively. Tables D-11 and D-12 present the HIs associated with ingestion of surface water (maximum detected concentration) for adults (chronic exposures; Table D-11) and children (chronic exposures; Table D-12).

As shown in Table 3-14 and Tables D-5b, D-6b and D-7b (Appendix D), using the PPRTV oral RfDs for sulfolane and the maximum concentration detected in offsite groundwater, the total estimated HIs associated with ingestion of groundwater are 12 for adult residents (chronic exposure; Table D-5b), 28 for child residents (chronic exposure; Table D-6b) and 7 for infant residents (subchronic exposure; Table D-7b),

respectively, based on ingestion of tapwater. Table 3-14 and Tables D-5c, D-6c and D-7c present the total estimated HIs associated with ingestion of homegrown produce, including an HI of 0.8 for adult residents (chronic exposure; Table D-5c), 2 for child residents (chronic exposure; Table D-6c) and 0.3 for infant residents (subchronic exposure; Table D-7c), respectively. These HIs are based on ingestion of homegrown produce using the USEPA (2012b) PPRTV oral RfDs for sulfolane, along with the maximum detected offsite sulfolane concentration, a BCF of 1.0 and the 95th percentile *per capita* produce ingestion rates. These exposure assumptions were used in all of the produce ingestion scenarios presented in this paragraph. As shown in Table 3-14 and Tables D-11 and D-12 (Appendix D), using the PPRTV oral RfDs for sulfolane and the maximum concentration EPC, the total estimated HIs associated with ingestion of surface-water are 0.03 for adult residents (chronic exposure; Table D-11) and 0.2 for child residents (chronic exposure; Table D-12). The surface-water HIs for this receptor group are the same for each EU (Table 3-15, Table 3-16a and Table 3-17a).

Table 3-14 presents the cumulative HIs for this receptor group for all exposure pathways combined based on maximum EPCs which are 13 for adult residents, 31 for child residents (chronic exposure), and 7 for infant residents (subchronic exposure). Table 3-14 also presents the cumulative ELCRs for this receptor group for all exposure pathways combined based on maximum EPCs which are 4 x 10^{-8} for adult residents, 9 x 10^{-9} for child residents (chronic exposure), and 1x 10^{-9} for infant residents (subchronic exposure).

Table 3-15 and Tables E-5a, E-6a and E-7a (Appendix E) present the estimated ELCRs and HIs for adults, children (chronic) and infant (subchronic) residents, respectively, based on inhalation of fugitive windborne dust or vapors from onsite COPCs in surface soil, assuming 95% UCL COPC concentrations. As shown in Table E-5a the total estimated ELCR is 4 x 10^{-8} and the total estimated HI is 0.001 for adult residents (chronic exposure; Table E-5a). For a child resident (chronic exposure), the total estimated ELCR is 9 x 10^{-9} and the total estimated HI is 0.001 (Table E-6a). The total estimated ELCR is 1 x 10^{-9} and the total estimated HI is 0.0007 for the infant resident (subchronic exposure; Table E-7a).

Assuming the 95% UCL concentration for sulfolane in EU-1, Table 3-15 and Tables E-5b, E-6b and E-7b in Appendix E) show estimated HIs based on ingestion of 95% UCL sulfolane concentrations in groundwater (i.e., tapwater) at EU-1 by resident receptors. Using the USEPA (2012b) PPRTV oral RfDs for sulfolane, the estimated HIs associated with ingestion of water are 5 for the adult resident (chronic exposure; Table E-5b), 11 for child resident (chronic exposure; Table E-6b) and 3 for infant resident (subchronic exposure; Table E-7b). Tables E-5c, E-6c and E-7c present the total estimated HIs associated with consumption of homegrown produce irrigated with water containing sulfolane in EU-1. The HIs are 0.3 for adult residents (chronic exposure), 0.9 for child residents (chronic exposure) and 0.1 for an infant resident (subchronic exposure), using the USEPA (2012b) PPRTV oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 3-16a and Tables D-13a, D-13b, D-14a, D-14b, D-15a and D-15b (Appendix D) present HIs based on ingestion of the maximum sulfolane concentration in groundwater (i.e., tapwater) within EU-2 for resident receptors. Using the USEPA (2012b) PPRTV oral RfDs for sulfolane, the total estimated HIs associated with ingesting tapwater containing maximum sulfolane concentrations in EU-2 are 4 for an adult resident (chronic exposure; Table D-13a), 9 for a child resident (chronic exposure; Table D-14a) and 2 for an infant resident (subchronic exposure; Table D-15a). In addition, Table 3-16a presents HIs associated with consumption of homegrown produce irrigated with groundwater containing the maximum sulfolane concentrations at EU-2. The estimated HIs for consumption of homegrown produce irrigated with water from EU-2 are 0.3 for an adult resident (chronic exposure; Table D-13b), 0.8 for a child resident (chronic exposure; Table D-14b) and 0.1 for an infant resident (subchronic exposure; Table D-15b), using the USEPA (2012b) PPRTV oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 3-16b and Tables E-11a, E-12a and E-13a (Appendix E) present HIs based on ingestion of the 95% UCL sulfolane concentration in groundwater (i.e., tapwater) within EU-2 for resident receptors. Using the USEPA (2012b) PPRTV oral RfDs for sulfolane, the total estimated HIs associated with ingesting tapwater containing sulfolane in EU-2 are 2 for an adult resident (chronic exposure; Table E-11a), 4 for a child resident (chronic exposure; Table E-12a) and 0.9 for an infant resident (subchronic exposure; Table E-13a). In addition, Table 3-16b and Tables E-11b, E-12b and E-13b (Appendix E) present HIs associated with consumption of homegrown produce irrigated with sulfolane-impacted groundwater at EU-2. The total estimated HIs for consumption of homegrown produce irrigated with water from EU-2 are 0.1 for an adult resident (chronic exposure; Table E-11b), 0.3 for a child resident (chronic exposure; Table E-12b) and 0.04 for an infant resident (subchronic exposure; Table E-13b) respectively, using the USEPA (2012b) PPRTV oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 3-17a and Tables D-19a, D-20a and D-21a (Appendix D) show the estimated HIs based on ingestion of the maximum sulfolane concentration in groundwater (i.e., tapwater) within EU-3 by resident receptors. Using the USEPA (2012b) PPRTV oral RfDs for sulfolane, the estimated HIs associated with ingestion of tapwater are 2 for an adult resident (chronic exposure; Table D-19a), 5 for a child resident (chronic exposure; Table D-20a) and 1 for an infant resident (subchronic exposure; Table D-21a). In addition to a drinking water scenario, Table 3-17a and Tables D-19b, D-20b and D-21b (Appendix D) present the HIs associated with consumption of homegrown produce irrigated with the maximum detected sulfolane concentration in groundwater in EU-3. The estimated HIs for consumption of homegrown produce are 0.1 for an adult resident (chronic exposure; Table D-19b), 0.4 for a child resident (chronic exposure; Table D-20b) and 0.06 for an infant resident (subchronic exposure; Table D-21b), using the USEPA (2012b) PPRTV oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 3-17b and Tables E-17a, E-18a and E-19a (Appendix E) show the estimated HIs based on ingestion of the 95% UCL sulfolane concentration in groundwater (i.e., tapwater) within EU-3 by resident receptors. Using the USEPA (2012b) PPRTV oral RfDs for sulfolane, the estimated HIs associated with ingestion of

tapwater are 0.3 for an adult resident (chronic exposure; Table E-17a), 0.7 for a child resident (chronic exposure; Table E-18a) and 0.2 for an infant resident (subchronic exposure; Table E-19a). In addition to a drinking water scenario, Table 3-17b and Tables E-17b, E-18b and E-19b (Appendix E) present the HIs associated with ingestion consumption of homegrown produce irrigated with sulfolane-impacted groundwater in EU-3. The estimated HIs for consumption of homegrown produce are 0.02 for an adult resident (Table E-17b), 0.05 for a child resident (chronic exposure; Table E-18b) and 0.007 for an infant resident (subchronic exposure; Table E-19b), using the USEPA (2012b) PPRTV oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

3.3.2.2.2 Offsite Indoor Commercial Workers

Table 3-14 and Table D-8 (Appendix D) show the HI based on ingestion of groundwater (i.e., tapwater), assuming the maximum offsite sulfolane concentration and the USEPA (2012b) PPRTV oral RfD for sulfolane. The total estimated HI is 9 for offsite indoor commercial/industrial workers (chronic exposure) based solely on ingestion of tapwater containing sulfolane (see Table D-8 [Appendix D]).

Table 3-15 and Table E-8 (Appendix E) show the HI based on ingestion of groundwater (i.e., tapwater), assuming the 95% UCL offsite sulfolane concentration for EU-1 and the USEPA (2012b) PPRTV oral RfD for sulfolane. The total estimated HI is 3 for offsite indoor commercial/industrial workers (chronic exposure) based solely on ingestion of tapwater containing sulfolane (see Table E-8 [Appendix E]).

At EU-2, two sulfolane groundwater EPCs were used to estimate potential hazards associated with ingestion of groundwater by offsite indoor commercial/industrial workers (chronic exposure). Using the maximum detected offsite sulfolane concentration at EU-2, the estimated HI is 3 (Table 3-16a). Comparatively, the HI based on the 95% UCL sulfolane concentration at EU-2 is 1. Both HIs were derived using the USEPA (2012b) PPRTV oral RfD for sulfolane (see Table D-16 [Appendix D] for maximum EPC and Table E-14 [Appendix E] for 95%UCL). Similarly, two sulfolane groundwater EPCs were used to estimate potential hazards associated with ingestion by offsite indoor commercial/industrial workers (chronic exposure) at EU-3. Table 3-17a shows the HI based on ingestion of groundwater (i.e., tapwater), assuming the maximum offsite sulfolane concentration at EU-3 and Table 3-17b shows the corresponding HI based the 95% UCL offsite sulfolane concentration at EU-3. Both HIs were derived using the USEPA (2012b) PPRTV oral RfD for sulfolane. Using the maximum detected sulfolane concentration at EU-3, the estimated HI is 2; the estimated HI is 0.2 for offsite indoor commercial/industrial workers (chronic exposure) based on the 95% UCL groundwater concentration at EU-3 (see Table D-22 [Appendix D] and Table E-20 [Appendix E], respectively).

3.3.2.2.3 Offsite Outdoor Commercial Workers

Table 3-14 presents the estimated ELCRs and HIs for offsite outdoor commercial workers potentially exposed via inhalation of dust particles from onsite surface soil (0 to 2 feet bgs), using 95% UCL COPC concentrations in onsite surface soil. The total estimated ELCR is 2×10^{-8} and the total estimated HI is 0.0006 (see Table D-9a [Appendix D]). Excluding the estimated arsenic concentrations in surface soil and HI, which are likely attributable to background, the total estimated ELCR is 2×10^{-8} and the total estimated HI is 0.0006 (Table D-9a). Table 3-14 also shows the HI for this receptor assuming ingestion of groundwater (i.e., tapwater) and assuming the maximum offsite sulfolane concentration. The estimated HI is 9 for offsite outdoor commercial/industrial workers, based on ingestion of tapwater (see Table D-9b [Appendix D]).

Table E-9a [Appendix E] shows ELCRs and HIs based on inhalation of fugitive windborne dust and vapors from onsite COPCs in surface soil, based on 95% UCL COPC concentrations and the USEPA (2012b) PPRTV oral RfD for sulfolane. It was assumed that the offsite outdoor commercial worker (chronic exposure) is located at the site boundary; therefore, the estimated ELCRs and HIs calculated for onsite commercial workers represent a health-protective estimate for an offsite commercial worker, based on inhalation of dust and vapors from the site. As shown in Table E-9a [Appendix E], the total estimated ELCR is 2×10^{-8} and the total estimated HI is 0.0006, based on inhalation of dust and vapors in ambient air (see Table E-9a [Appendix E]).

Assuming the 95% UCL and USEPA (2012b) PPRTV oral RfD for sulfolane in EU-1, the total estimated HI is 3 for offsite outdoor commercial/industrial workers (chronic exposure), based on ingestion of groundwater (see Table 3-15 and Table E-9b [Appendix E]).

At EU-2, two sulfolane groundwater EPCs were used to estimate potential hazards associated with ingestion of groundwater: the maximum detected concentration of sulfolane and the 95% UCL of the mean sulfolane concentrations. Using the maximum detected concentration in groundwater at EU-2, the estimated HI is 3 for offsite outdoor commercial/industrial workers (chronic exposure) based on ingestion of groundwater (see Table 3-16a and Table D-17 [Appendix D]). Using the 95% UCL sulfolane concentration, the total estimated HI is 1 for offsite outdoor commercial/industrial workers at EU-2, based on ingestion of tapwater (chronic exposure; see Table 3-16b and Table E-15 [Appendix E]). Both hazard estimates used the USEPA (2012b) PPRTV oral RfD for sulfolane.

Similarly, at EU-3, the 95% UCL and maximum sulfolane groundwater concentrations were both evaluated as distinct EPCs to estimate potential hazards associated with ingestion of groundwater by offsite commercial/industrial workers. Using the maximum sulfolane concentration at EU-3, the estimated HI is 2 (Table 3-17a and Table D-23 [Appendix D]). Using the 95% UCL sulfolane concentration, the estimated HI is 0.2 for offsite outdoor commercial/industrial workers at EU-3 (see Table 3-17b and Table E-21 [Appendix E]). Both hazard estimates are used the USEPA (2012b) PPRTV oral RfD for sulfolane.

3.3.2.2.4 Offsite Construction/Trench Workers

The estimated HIs for an offsite construction worker who is potentially exposed to maximum sulfolane concentrations by incidental ingestion of sulfolane in offsite groundwater in excavation trenches is 0.0008 (see Table 3-14 and Table D-10 [Appendix D]). This exposure is subchronic and the HI is derived assuming the maximum offsite sulfolane concentration and using the USEPA (2012b) PPRTV subchronic oral RfD for sulfolane. As discussed in Section 3.1.1.4, sulfolane is not considered to pose adverse health effects due to inhalation and dermal contact exposures. The total estimated HI is 0.0008 for offsite construction workers, based on incidental ingestion of groundwater while working in trenches.

Tables 3-15, 3-16b and 3-17b show the HIs for potential exposures by the construction worker (subchronic exposure) based on 95% UCL sulfolane concentrations for incidental ingestion of sulfolane in offsite groundwater in excavation trenches in EU-1, EU-2 and EU-3, respectively. The estimated HIs for offsite construction workers, which are based on the USEPA (2012b) PPRTV subchronic oral RfD for potential groundwater ingestion exposures of groundwater while working in trenches, and 95%UCL sulfolane concentrations, are 0.0003, 0.0001 and 0.00002 in EU-1, EU-2 and EU-3, respectively (see Tables E-10, E-16 and E-22 [Appendix E] for the hazard calculations for this receptor in EU-1, EU-2 and EU-3, respectively). Tables 3-16a and 3-17a show the corresponding HIs for this receptor group based on the maximum sulfolane groundwater concentrations at EU-2 and EU-3, respectively. The estimated HIs for offsite construction workers exposed to maximum groundwater concentrations at EU-2 and EU-3 are 0.0003 and 0.0001, respectively (see Tables D-18 and D-24 [Appendix D]).

3.3.2.2.5 Offsite Adult and Child Recreational Users

Table 3-14 and Tables D-11 and D-12 (Appendix D) show the estimated HIs for offsite adult and child (aged 1 to 6years) recreational users (i.e., swimmer who may be exposed by incidental, ingestion of sulfolane in surface water), assuming the maximum offsite sulfolane concentration in pore water and the USEPA (2012b) PPRTV chronic oral RfD for sulfolane. The total estimated HIs are 0.03 and 0.2 for offsite adult (chronic exposure) and child recreational users (chronic exposure), respectively.

3.3.3 Conclusions for Provisional Peer Reviewed Toxicity Value Scenario

Results of this Revised Draft Final HHRA indicate that the estimated ELCRs and HIs, based on maximum onsite COPC concentrations, are at or below the ADEC- established acceptable ELCR of 1×10^{-5} for current and future onsite indoor and outdoor commercial/industrial workers and adult site visitors, and below the target HI of 1 for the PPRTV Scenario. The estimated ELCRs and HIs for current and future onsite construction workers exceed the acceptable ELCR of 1×10^{-5} and target HI of 1 based on maximum COPC concentrations; however, estimated ELCRs are below the acceptable ELCR based on 95% UCL COPC concentrations.

Table 3-14 presents the estimated ELCRs and HIs using maximum COPC concentrations in onsite subsurface soil, maximum onsite COPC surface soil and groundwater concentrations, the single maximum offsite groundwater concentration of sulfolane, and the USEPA (2012b) PPRTV oral RfDs for sulfolane. The estimated HIs are below the target HI of 1 for the onsite commercial/industrial worker, onsite commercial/industrial outdoor worker, onsite visitor and offsite child recreator. The estimated HIs exceed the target HI of 1 for onsite construction/trench workers, offsite residents, and offsite indoor and outdoor commercial workers. The HI is equal to 49 for onsite construction workers based on inhalation of volatile COPCs in trench air from groundwater. Benzene, naphthalene, xylenes and 1,3,5-trimethyl benzene are the hazard drivers. For offsite adult, child and infant resident receptors, the HIs are equal to 13, 31, and 7, respectively.

Similarly, the estimated total ELCRs for the potential onsite visitor (Table 3-14) are below the ADEC acceptable ELCR of 1×10^{-5}. The estimated total ELCRs for the onsite indoor and outdoor commercial workers and onsite construction/trench workers do not exceed the ADEC acceptable ELCR. The total estimated ELCRs are equal to 1×10^{-5} and 5×10^{-6} for onsite indoor and outdoor commercial workers, respectively. The estimated ELCR for the indoor commercial worker is based on inhalation of volatile COPCs in indoor air. For the outdoor commercial worker, the estimated total ELCR is based on soil ingestion including arsenic, which is likely present due to background concentrations. For onsite construction/trench workers, the total estimated ELCR is equal to 3×10^{-4} for onsite construction/trench workers, which is based primarily on inhalation of volatile COPCs in trench air from groundwater, with benzene, naphthalene and ethylbenzene as the primary risk drivers.

Table 3-15 presents the estimated ELCRs and HIs using 95% UCL COPC concentrations in onsite soil and in EU-1, and the USEPA (2012b) PPRTV oral RfDs for sulfolane. Using the 95% UCL onsite COPC soil concentrations, the 95% UCL onsite and EU-1 offsite sulfolane groundwater concentrations, and the USEPA (2012b) PPRTV oral RfDs for sulfolane, the estimated HIs for the receptors evaluated are below the target HI of 1, with the exception of onsite construction/trench workers, offsite residents, and offsite indoor and outdoor commercial workers. The HI is equal to 9 for onsite construction workers based on inhalation of volatile COPCs in trench air from groundwater. Naphthalene and benzene are the hazard drivers. For offsite residents, the estimated total HIs are equal to 5, 12 and 3 for offsite adult, child and infant residents, respectively, with ingestion of sulfolane in tap water the primary hazard driving exposure pathway. For both the offsite indoor commercial worker and the offsite outdoor commercial worker, the estimated HI is 3, based on ingestion of sulfolane in groundwater.

Similarly, the estimated total ELCRs for the potential receptors evaluated at EU-1 are at or below the ADEC acceptable ELCR of 1×10^{-5}, with the exception of onsite commercial/ industrial outdoor workers and onsite construction/trench workers (Table 3-15). For the onsite commercial/ industrial outdoor worker, the total estimated ELCR is equal to 5×10^{-6}. The total estimated ELCR is equal to 3×10^{-5} for onsite

construction/trench workers, which is based on inhalation of volatile COPCs in trench air from groundwater with benzene as the risk driver.

Table 3-16a presents the estimated ELCRs and HIs using the maximum COPC sulfolane concentrations in EU-2. Under the PPRTV Scenario using maximum COPC concentrations in EU-2, the HI for offsite construction workers is below the target HI of 1. The estimated HIs exceed the target HI of 1 for offsite adult, child (chronic exposure) and infant residents (subchronic exposure); and offsite indoor and outdoor commercial workers. Ingestion of sulfolane in groundwater is the primary exposure pathway. Using the maximum sulfolane concentration in EU-2, the HI for offsite construction workers is below the target HI of 1.

As shown in Table 3-16b, using the 95% UCL COPC sulfolane concentrations in EU-2, the estimated HIs are either below or equal to the target HI of 1 for offsite infant resident, offsite indoor and outdoor commercial/ industrial worker receptors, and offsite construction workers. The HIs exceed the target HI of 1 for offsite resident adult and child (chronic) receptors, with ingestion of tapwater containing sulfolane as the primary hazard driver.

Table 3-17a presents the estimated ELCRs and HIs using the maximum sulfolane concentrations in EU-3. Under the PPRTV Scenario, HIs exceed the target HI of 1 for offsite adult and child (chronic) residents and for indoor and outdoor commercial/industrial workers. Ingestion of groundwater is the primary exposure pathway. The HI for offsite construction workers is below the target HI of 1.

As shown in Table 3-17b, using the 95% UCL sulfolane concentrations in EU-3, the estimated HIs are below the target HI of 1 for each of the potential offsite receptors.

3.4 Evaluation of Potential Exposures to Lead in Onsite Groundwater

The USEPA's (2009b) ALM was used to evaluate current and future onsite outdoor commercial/industrial workers and construction/trench workers potentially exposed to lead in onsite groundwater. The maximum concentration of lead detected above the laboratory reporting limit in onsite groundwater is 2.05 µg/L. The USEPA's threshold lead concentration of 10 µg/dL of whole blood is based on potentially adverse neurological effects in children (CDC 2011). The 95th percentile blood lead concentration (PbB) among fetuses of onsite adult workers, assuming potential exposure to the maximum detected concentration in onsite groundwater, was calculated using the ALM (USEPA 2009b). Using the groundwater ingestion rates and exposure frequencies for current and future onsite outdoor commercial/industrial workers and construction/trench workers presented in Table 3-12, the calculated probabilities that fetal PbBs are greater than10 µg/dL are 0.005 and 0.002%, respectively. Thus, potential exposures to lead in groundwater at the site are below the regulatory level of concern and are not expected to pose adverse health effects to current and future onsite outdoor commercial/industrial workers and construction/trench workers. The Calculations of Blood Lead Concentrations spreadsheet is provided in Appendix I.

Based on the results of the ALM (USEPA 2009b), the maximum detected concentration of lead in onsite groundwater is not expected to pose adverse health effects to current and future onsite outdoor commercial/industrial workers or construction/trench workers.

3.5 Uncertainty Assessment – PPRTV Scenario

Each exposure parameter value and toxicity value incorporated into the HHRA is associated with some degree of uncertainty; these uncertainties may contribute to an overestimation or underestimation of risks at the site (ADEC 2011c). Therefore, key uncertainties associated with each HHRA component (i.e., data evaluation, COPC selection, toxicity assessment, exposure assessment and risk/hazard characterization) were evaluated.

3.5.1 Data Evaluation

Soil and onsite groundwater samples were analyzed for a large suite of constituents from multiple samples collected throughout the site over time. These samples were analyzed using accepted analytical methodologies. It is unlikely that constituents were overlooked or underestimated by the analytical methods employed. The laboratory method used for soil sulfolane analyses in 2010 and 2011 was not final at the time, but the analytical results have been validated with an approved method.

The release-related constituents detected in soil (e.g., BTEX) were measured in more than 250 soil samples, of which 88 were surface soil samples. The large data set provides high confidence in the 95% UCL on the mean concentrations and in the representativeness of the use of this statistic for EPCs.

A large number of samples of key constituents detected at the site are available for use in the data evaluation. For example, for sulfolane in offsite groundwater, more than 429 samples were grouped by concentration ranges with each range having a high number of samples to represent that zone (i.e., 105 samples in the greater than 100 µg/L EU, 72 samples in the greater than 25 µg/L EU and 252 samples in the EU with detections up to 25 µg/L). The number of samples increases the representativeness of the EPCs based on these groupings of data and it is unlikely that the EPC based on the 95% UCL on the mean concentration underestimates potential exposures to sulfolane given the number of samples. The maximum detected concentration of sulfolane (443 µg/L) is 1.4 times higher than the next highest detection of sulfolane in offsite wells and 3 times greater than the 95% UCL on the mean concentration for the greater than 100 µg/L EU.

Data for onsite wells with multiple sampling rounds were averaged together and these temporal average well concentrations were grouped to calculate 95% UCL concentrations on the mean. Each temporal average concentration represents multiple sampling events and provides a reliable measure of constituent concentrations in that well. Grouping the data by well to estimate EPCs reduced the number of samples

upon which the statistical analysis could be based. Where too few wells were available to reliably estimate 95% UCL values, the highest temporal well average was used to represent the EPC, which is an overestimate of potential exposure.

3.5.2 Constituent of Potential Concern Selection

COPCs were selected from a list of COIs known or suspected to have been used at the site. The approaches used to characterize the site were intended to identify the COPCs in environmental media associated with current and historical site operations. Sampling events were sequentially conducted based on the knowledge obtained from past sampling events. It is likely that these events identified the majority of areas with residual COPCs. While it is possible that some substances may have been omitted, the probability of those substances being important in driving risk is expected to be low. The suite of analyses that was selected represents those constituents that would most likely result from site operations and are therefore the most relevant and appropriate constituents for estimating risks and hazards. Note that analyses of isopropanol and propylene glycol were inadvertently missed during recent groundwater sampling events. Although the potential presence of these constituents is not expected to change the outcome of the risk evaluation, these COPCs will be evaluated once data have been collected.

3.5.3 Toxicity Assessment

Dose-response values are sometimes based on limited toxicological data. For this reason, a margin of safety is built into estimates of both carcinogenic and noncarcinogenic risk, and actual risks are lower than those estimated. The two major areas of uncertainty introduced in the dose-response assessment are: (1) animal to human extrapolation and (2) high to low dose extrapolation. These are discussed below.

Human dose-response values are often extrapolated, or estimated, using the results of animal studies. Extrapolation from animals to humans introduces a great deal of uncertainty in the risk assessment because in most instances, it is not known how differently a human may react to the constituent compared to the animal species used to test the constituent. The procedures used to extrapolate from animals to humans involve conservative assumptions and incorporate several uncertainty factors that overestimate the potential adverse effects associated with a specific dose. As a result, overestimation of the potential for adverse effects to humans is more likely than underestimation.

Predicting potential health effects from exposure to media containing COPCs requires the use of models to extrapolate the observed health effects from the high doses used in laboratory studies to the anticipated human health effects from low doses experienced in the environment. The models contain conservative assumptions to account for the large degree of uncertainty associated with this extrapolation (especially for potential carcinogenic effects) and therefore, tend to be more likely to overestimate than underestimate potential risks.

Oral RfDs for sulfolane have been derived using different approaches and laboratory studies. For the PPRTV Scenario, the USEPA (2012b) PPRTV chronic oral RfD of 0.001 mg/kg-day and PPRTV subchronic oral RfD of 0.01 mg/kg-day were used to derive HIs. In the ARCADIS Comparative Scenario, alternate chronic and subchronic RfDs of 0.01 mg/kg-day and 0.1 mg/kg-day that were derived by ARCADIS from scientific literature were used to derive HIs. As expected, with the alternate sulfolane oral RfD values, the HIs decrease. The reasoning for the ARCADIS derivation is provided in Section 4 and Appendices H and K.

3.5.4 Exposure Assessment

According to USEPA (2001) guidance, screening-level estimates of exposure and risk calculations use assumptions that maximize the estimate of risk to ensure that only those constituents that represent a *de minimis* risk are eliminated from further consideration, and those that potentially pose an unacceptable risk will be retained for consideration in subsequent steps of the risk assessment process. As requested by the ADEC, maximum concentrations of COPCs were used as EPCs in the risk calculations for the potential receptors evaluated for the PPRTV Scenario. More often, a conservative estimate of average concentrations of constituents is used to represent EPCs (USEPA 1989, 2002c, 2006b, 2007). Potential receptors are more likely to be exposed to a range of these concentrations represented by the average or 95% UCL concentration.

Concentrations of VOCs in indoor air of current and future onsite commercial/industrial structures were estimated using concentrations of VOCs in groundwater at the site. Due to the uncertainties associated with partitioning from soil to soil gas, ITRC (2007b) does not recommend using soil data as a source of COPCs to evaluate potential vapor intrusion. Thus, use of soil data to evaluate potential soil vapor concerns is inappropriate. USEPA (2002a) and ITRC (2007a) recommendations concluded that there is insufficient scientific support for this procedure. ITRC (2007a) notes “Scientific studies have failed to show good correlation between soil and soil gas sampling and analysis on a consistent basis.” They conclude by recommending that soil data should be used only as a secondary line of evidence and not as a primary line. Overall, the scientific evidence indicates that use of soil data is not a reliable approach for identifying potential vapor intrusion concerns.

Dermal contact with COPCs in groundwater by current and future onsite outdoor commercial/industrial workers was considered an insignificant exposure pathway. Onsite use of groundwater beneath the site is limited to infrequent fire extinguishing. Fires at the site are very rare and the period of exposure would likely be relatively very short. Thus, exclusion of this potential exposure pathway would not significantly impact ELCR and HI estimates for these possible onsite receptors.

For the offsite CSM, it was assumed that groundwater may be connected with surface water, and pore-water data were collected to evaluate potentially complete exposure pathways for surface water. Pore-water piezometer installation methods needed to be revised for two of the three offsite locations because the

surface-water body was frozen and pore-water samples could not be collected. However, the groundwater samples collected were able to be evaluated for human health risk. Because sulfolane degrades more rapidly in the presence of nutrients and oxygen that would be present in the surface water (ADHSS 2010), and given the limited groundwater-surface water interchange due to a frozen surface-water body, the groundwater collected adjacent to two of the three surface-water bodies in 2012 likely overestimates the surface water concentrations at those locations. Thus, the data used for the swimming scenario overestimate human health risk.

Ingestion of offsite groundwater by current and future offsite residents was the primary exposure pathway for these potential receptors and resulted in the relatively highest HIs, including for infants (0 to 1 year). The ingestion rate used for this age group slightly exceeded that used for children (0 to 6 years). It was also assumed that infants do not breastfeed and that their formula was made with tapwater instead of pediatrician-recommended distilled water. Thus, it is highly likely that HI estimates for this receptor were overestimated.

Only potential ingestion exposures were quantitatively assessed for sulfolane. This analysis suggests that dermal contact and inhalation exposure routes are not significant for sulfolane, which is supported by ATSDR (2010 and 2011) Health Consultations and animal studies (Brown et al. 1966, Andersen et al. 1977). Although these exposure routes were excluded, inclusion of them would likely not contribute significantly to overall hazard estimates. As described in Section 3.1.1.4, dermal contact and inhalation exposure routes are not significant for sulfolane. These assumptions are based on animal studies that have shown that sulfolane is not readily absorbed through human skin because of its low permeability and is not expected to pose a significant risk via an inhalation exposure route due to its low volatility. Ingestion of sulfolane in impacted environmental media is the appropriate exposure route to assess potential hazards to on and offsite receptors. Estimated hazards based on inhalation and dermal exposure routes are insignificant relative to hazards estimated based on the ingestion exposure route.

The ingestion rates of homegrown fruit and vegetables for offsite residents are not known. In the PPRTV Scenario, ingestion of fruit and vegetables by offsite residents was evaluated based on an assumed consumption rate equivalent to 95% of the population. As is described in the Uncertainty Assessment in Section 4, ARCADIS selected mean *per capita* ingestion rates.

HIs using the mean *per capita* ingestion rates would be approximately five times lower for the ingestion of produce exposure pathway. For the PPRTV Scenario, a groundwater-to-produce BCF value of 1 was assumed. HIs for the ingestion of homegrown produce pathway calculated using a BCF of 0.32 (the derivation of which is described in Section 4.5.4) would be approximately three times lower than the HIs calculated in the PPRTV Scenario. The cumulative impact of using both the mean per capita ingestion rates (factor of approximately 2.8) and a BCF of 0.32 (factor of approximately 3.1) result in HIs that are approximately nine times lower than the HIs calculated in the PPRTV Scenario. However, even using high

end exposure and uptake assumptions for ingestion of homegrown produce, this is an insignificant exposure pathway compared to ingestion of groundwater.

In the PPRTV Scenario, swimming was assumed to occur 60 days per year for 1 hour per day with surface-water ingestion rates at the maximum ingestion rate for adults and the 97th percentile ingestion rate for children age 18 and under. HIs based on an EF of 30 days per year for 0.5 hour per day at recommended mean value ingestion rates (USEPA, 2011a), which are the exposure parameters selected by ARCADIS as described in the Uncertainty Assessment in Section 4, would be approximately ten times (a factor of 9.7) lower than those calculated for the PPRTV Scenario.

3.5.5 Risk/Hazard Characterization

Some HIs exceed the USEPA and the ADEC acceptable target HI equal to 1, particularly those estimated for onsite construction/worker exposures to volatile COPCs in the air of a trench, which have been modeled from groundwater concentrations. For this Revised Draft Final HHRA, endpoint-specific HIs were not calculated and summing all HQs regardless of endpoint is a health-protective approach. The USEPA acknowledges that adding all HQ or HI values may overestimate hazards, because the assumption of additivity is likely appropriate only for those chemicals that exert their toxicity by the same mechanism (USEPA 1989). Application of endpoint-specific HIs is expected to reduce total HI estimates.

The child scenario has been assessed in this section using the chronic oral reference dose, which is by definition a daily dose that is protective for sensitive receptors for lifetime exposures. Many USEPA programs such as the drinking water program use adult scenarios to protect both adults and children. For instance, Federal drinking water standards are derived using adult receptors, and USEPA states that such standards are protective for both adults and children. The use of the child exposure levels and body weights coupled with a chronic reference dose in this section provides an additional margin of exposure, but it is uncertain whether it provides additional public health protection. Appendices H and K provide additional information on sulfolane's toxicological profile. These documents show that sulfolane presents no special concerns to children, and that focusing public health protection efforts on adult receptors using a chronic reference dose adequately protects children.

4. ARCADIS Comparative Scenario

This section presents the ARCADIS Comparative Scenario estimated ELCRs and HIs for the same potentially complete and significant exposure pathways identified in Section 3.1.1.4 for the same potential receptors located on and offsite. In this section, the toxicity value for sulfolane that was selected by ARCADIS, as described in Appendix H, is used, with the same exposure parameters presented in Table 3-12. For each total estimated ELCR and HI, the primary exposure pathway and COPC(s) are indicated, as appropriate. In the ARCADIS Comparative Scenario, chronic oral RfDs were used to evaluate child exposures. Child and subchronic oral reference doses were used to evaluate child exposures in the ARCADIS Scenario, presented in the Uncertainty Assessment (Section 4.5.4) Supportive reasoning for these choices is provided in Appendices H and K.

4.1 Exposure Assessment

ARCADIS conducted an HHRA to evaluate the potential for human health risk from exposure to site-related constituents, following protocols presented in the June 8, 2000 ADEC Risk Assessment Procedures Manual that are adopted into regulation in 18 AAC 75. The primary ADEC references for this Revised Draft Final HHRA include the Draft Risk Assessment Procedures Manual (ADEC 2010a and 2011d), Cleanup Levels Guidance (ADEC 2008a), Cumulative Risk Guidance (ADEC 2008b), and 18 AAC 75 Oil and Other Hazardous Substances Pollution Control guidance (ADEC 2008c). Other references used include RAGS (USEPA 1989, 1991, 2001, 2004a and 2009a), Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (USEPA 2002a), Vapor Intrusion Pathway: A Practical Guide (ITRC 2007a) and Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios (ITRC 2007b).

4.1.1 Human Health Conceptual Site Models

Two preliminary human health CSMs (one onsite CSM and one offsite CSM) were prepared and submitted to the ADEC with the Site Characterization Work Plan (Barr 2010b). After this submittal, a substantial amount of additional site assessment data was collected and in April 2011 the updated CSMs were submitted to the ADEC to reflect the enhanced understanding of site conditions. In the RAWP submitted to ADEC in December 2011 (ARCADIS 2011a), the CSMs were further refined to better reflect existing site conditions. The updated CSMs were developed following the Human Health Conceptual Site Model Graphic and Scoping Forms and the Policy Guidance on Developing Conceptual Site Models (ADEC 2010b and 2010c, respectively). Due to the significant difference in COPC occurrence onsite (petroleum hydrocarbon constituents and sulfolane) versus offsite (sulfolane only), two human health CSM graphic forms (Figures 3-1 and 3-2) were prepared and updated to more clearly portray and distinguish potential exposure pathways for possible on- and offsite receptors.

This section describes the CSMs submitted to the ADEC in December 2011 and revisions to the offsite CSM based on ADEC comments discussed during the meeting held on January 24, 2012. Human health CSMs for on- and offsite locations are presented on Figures 3-1 and 3-2, respectively, and are discussed in the following subsections.

4.1.1.1 Potential Sources

During site operations, various materials associated with the crude oil refining process have been released in operating areas of the site, including the crude oil processing units, extraction unit, loading racks, wastewater lagoons, sumps and drain systems. In addition, spills and/or leaks to surface soil from ASTs, pumps and associated piping during routine operations constitute potential sources of petroleum constituents at the site. Petroleum hydrocarbons have also been detected in historical groundwater samples collected from onsite monitoring wells.

Onsite impacted environmental media may include surface (0 to 2 feet bgs) and subsurface (to a depth of 15 feet bgs, the maximum depth at which human exposure is likely to occur) soil, groundwater, indoor and outdoor air, surface water, sediment and biota. Offsite impacted media may include groundwater, surface water, sediment, wild food (such as fish) and homegrown produce.

4.1.1.2 Potential Fate and Transport Mechanisms

As described in Section 4.1.1.1, the primary sources of COPCs are spills and releases to soil and groundwater during facility operations. COPCs may be retained in site soils or subject to constituent fate and transport mechanisms at the site. Fate and transport mechanisms may include soil sorption; biodegradation; wind erosion and transport; migration to groundwater; advective/dispersive transport in groundwater, on or offsite; and volatilization into soil gas, outdoor air or indoor air.

Potential current and future onsite receptors may be directly exposed to COPCs in surface and subsurface soil via incidental ingestion, dermal contact and inhalation of dust particles in air. In addition, COPCs adhered onto dust particles may migrate from exposed surface or subsurface soil to outdoor air and be breathed by potential offsite receptors. When bound to surface soils, compounds sorbed to soil particles may be subject to wind erosion and windblown transport in outdoor air. Due to the nature of the site, the majority of operational areas are covered with asphalt pavement or gravel. However, exposed and unpaved areas do exist at the site. Therefore, although limited, windborne particulate transport is possible at the site, and this potential pathway was evaluated during the HHRA.

COPCs may leach from soil to groundwater by percolation or may have been directly released to groundwater. Based on groundwater samples collected from onsite wells, sulfolane is the only COPC that is known to have migrated offsite. Potential direct-contact exposures to COPCs in groundwater (e.g., tapwater

ingestion and inhalation of volatiles in water) are not expected to occur for current and future onsite commercial/industrial workers because onsite groundwater is only used for industrial purposes (e.g., fire suppression). However, current and future onsite outdoor commercial/industrial receptors may be exposed to COPCs in groundwater by dermal contact while extinguishing fires, if they occur. In addition, due to the relatively shallow average depth to groundwater onsite (historically from 8 to 10 feet bgs), current and future onsite construction/trench workers may be exposed by incidental ingestion of and dermal contact with COPCs in groundwater that has pooled in excavated trenches.

The city provides municipal water for drinking and other potable uses at the site. Current onsite receptors consume drinking water from a municipal source and are expected to consume drinking water from this source in the future. Current and future offsite receptors may be exposed to sulfolane in groundwater that has migrated from the site to wells used for tapwater. In addition, groundwater may be used offsite to irrigate homegrown produce. Sulfolane in groundwater may be taken up by homegrown produce and consumed by offsite residents.

Onsite surface water consists of water that is stored in two lagoons and two gravel pits. Runoff and erosion from soil to surface water may be transport mechanisms. Groundwater from the site flows offsite in a north-northwesterly direction and groundwater is recharged by surface water from the Tanana River. COPCs in groundwater may eventually flow to offsite surface-water bodies and to sediment, which may be contacted by offsite recreational users. Pore-water data were collected to evaluate the potential for exposure at the groundwater/surface-water interface. Some of the samples used for this HHRA were collected when the adjacent surface-water body was frozen; therefore, the degree of connectivity with the surface water, if any, could not be established.

For this HHRA, potential ingestion of sulfolane in surface water by adult and child recreational users while swimming is considered a potentially complete exposure pathway offsite. The collected pore-water samples likely reflect higher sulfolane concentrations than would be expected in true pore-water samples because of limited surface water to groundwater interchange during frozen conditions. Pore-water samples will generally reflect higher sulfolane concentrations than would be encountered by actual recreational users of the surface water bodies because sulfolane degrades more rapidly in the presence of nutrients and oxygen that would be present in the surface water (ADHSS 2010). Accordingly, the data presented in this Revised Draft Final HHRA provide a health-protective assessment of risk to swimmers.

Volatilization is another fate and transport mechanism at the site for lighter petroleum hydrocarbon compounds and other VOCs. VOCs may volatilize from subsurface soil into soil gas, with eventual diffusion and/or advection into outdoor air and/or indoor air in onsite buildings. VOCs may also leach from soil to groundwater, where dissolved-phase VOCs may be transported downgradient both on and offsite. VOCs may volatilize from shallow exposed groundwater in excavations directly into outdoor air. VOCs may volatilize from groundwater into soil gas, with eventual diffusion and/or advection into outdoor air

and/or indoor air of on- and/or offsite buildings. VOCs may also be subject to degradation by microorganisms in subsurface soils and groundwater. Heavier petroleum hydrocarbon compounds, such as PAHs, adsorb to solids and do not tend to volatilize. As such, these compounds generally tend to remain in place, where they are subject to aerobic biodegradation by microorganisms. Sulfolane is not expected to volatilize under the conditions observed at the site, as discussed in Section 4.1.1.4.

4.1.1.3 Potential Receptors

Potential human receptors were identified based on current and reasonably foreseeable future land use at the site. A review of current and future land use identified the following potential human receptors at the site.

- **Current and future onsite indoor commercial/industrial workers** were considered to be individuals from 18 to 65 years old. It was assumed that these receptors perform commercial and/or industrial work activities (e.g., office work, laboratory analyses, shipping or warehouse inventory management) indoors onsite, under current or future (redeveloped) land use scenarios. Potential exposures to COPCs in soil are considered to be insignificant for onsite indoor commercial/industrial workers. These potential receptors may be exposed to COPCs in indoor air during a standard 40-hour work week for 25 years, for 250 days per year. Potential inhalation of outdoor air is insignificant. Inhalation of VOCs in indoor air was evaluated following USEPA (2009a) RAGS Part F.

- **Current and future onsite outdoor commercial/industrial workers** were considered to be individuals from 18 to 65 years old. These receptors were assumed to perform commercial and/or industrial work activities (e.g., maintenance work for ASTs or associated piping) outdoors at the site under current or future (redeveloped) land use scenarios. These individuals may occasionally use site groundwater for industrial purposes (e.g., fire suppression). Direct-contact exposures with groundwater are considered insignificant because fires are rare onsite and the exposure period is expected to be short. This exposure pathway was not quantitatively evaluated. These potential receptors may be exposed to COPCs in site media during a standard 40-hour work week for 25 years, for 250 days per year. Following ADEC (2010a) guidance, it was assumed that onsite outdoor workers with an average BW of 70 kg are exposed to 100 mg/day COPCs in surface soil and that 100 percent of the FI is from onsite surface soil.

  FHRA requires all onsite workers to wear long-sleeved shirts, long pants and shoes. Thus, the adult commercial/industrial worker outdoor receptor was assumed to wear a long-sleeved shirt, long pants and shoes, which limits the exposed skin surface to the head and hands. The recommended USEPA (2011a) SSA exposed to impacted soil for the adult commercial/industrial worker outdoor receptor is 2,230 cm^2, which is the average of the adult male and adult female mean values for head and hands. The USEPA (2004a) recommended weighted soil-to-skin AF for a commercial/industrial adult worker of

0.2 mg/cm^2 based on the 50th percentile weighted AF for utility workers (i.e., the activity determined to represent a high-end contact activity) was used. Potential inhalation of indoor air was considered insignificant for the outdoor commercial/industrial worker. Inhalation of volatile COPCs and dust in outdoor air was evaluated following USEPA (2009a) RAGS Part F.

- **Current and future onsite construction/trench workers** were considered to be individuals from 18 to 65 years old. These receptors were assumed to perform short-term maintenance and emergency repair activities on underground utilities or facility piping at the site. These receptors may be exposed to COPCs in surface and/or subsurface soil during the work day while performing the maintenance and/or repair task. Because the depth to groundwater at the site generally ranges from 8 to 10 feet bgs, construction/trench workers may be exposed to COPCs in groundwater that has pooled in a trench during performance of the maintenance and/or repair task. It was assumed that the same worker will provide maintenance and/or repair tasks.

  Potential construction/trench worker receptors were assumed to be exposed to COPCs in onsite soil (down to a depth of 15 feet bgs) and groundwater for 1 hour each day of a standard 5-day work week, for 125 days, for 1 year. This EF is a modification from that proposed in the RAWP (250 days per year). This deviation is justified because most of the utilities at the site are located aboveground and trenching activities typically do not occur during 6 months of each year, when the ground is frozen. It is assumed that soil may be accessible for trenching activities (i.e., not frozen) for 6 months per year.

  Construction/trench workers with an average BW of 70 kg are assumed to be exposed to 330 mg/day (USEPA 2002b) of COPCs in surface and subsurface soil, and 100 percent of the FI is assumed to be from surface and subsurface soil. It was assumed that onsite construction/trench workers incidentally ingest 0.0037 L/day of groundwater pooled in a trench. This rate is based on the mean ingestion rate for wading/splashing presented in the USEPA (2011a) EFH Table 3-93 (3.7 milliliters per hour * 1 hour per day). This consumption rate is likely to overestimate actual exposure, because dewatering usually occurs at excavation sites where water has pooled in trenches.

  FHRA requires all onsite workers to wear long-sleeved shirts, long pants and shoes. Therefore, the onsite adult construction worker receptor was assumed to wear a long-sleeved shirt, long pants and shoes, and the exposed SSA was limited to the head and hands. The USEPA (2011a) recommended SSA exposed to impacted soil for the adult construction worker receptor is 2,230 cm^2. The USEPA (2002b) recommended weighted soil-to-skin AF for a construction worker of 0.3 mg/cm^2-day was used. Inhalation of volatile COPCs and dust in outdoor air were evaluated following USEPA (2009a) RAGS Part F.

- **Current and future onsite visitors and trespassers.** Occasional visitors or trespassers may also be present onsite. However, the site does not and is not expected to attract trespassers because of the

character and location of the site (i.e., an industrial setting with controlled access). Moreover, it is anticipated that a trespasser's exposure at the site would be very infrequent. Onsite visitors are typically adults with limited access across the site. Children rarely visit the site. Thus, potential direct-contact exposures to COPCs in soil and groundwater by current and future onsite trespassers and visitors are insignificant. Potential inhalation of outdoor air is also insignificant. However, assuming the adult visitor is located in an onsite building, inhalation of volatile COPCs in indoor air by this potential receptor was evaluated following USEPA (2009a) RAGS Part F. Current and future onsite adult visitors (18 to 65 years of age) are assumed to be exposed to COPCs in indoor air for 2 hours per day, 12 days per year for 30 years.

- **Current and future offsite residents** were evaluated as infants (0 to 1 year of age), children (1 to 6 years of age) and adults (18 to 65 years of age). HHRAs do not typically focus on infant exposures as a separate receptor group, but infants are included here because the ATSDR (2011) and the ADHSS (2012) have addressed infants as a separate receptor group in their Health Consultations. There is evidence that sulfolane does not present a significant risk for developmental effects and it is not mutagenic, mitigating infant-specific exposure concerns. Resident receptors were assumed to be located downgradient of the site and may be exposed to sulfolane in groundwater that has migrated from the site. No other COPCs associated with site operations are known to be present in offsite groundwater. These potential offsite receptors may ingest sulfolane in groundwater as tapwater. In addition, it was assumed that these potential receptors consume homegrown produce, which may have taken up sulfolane from groundwater. It was assumed that potential resident receptors may be exposed to sulfolane in tapwater for a 1-, 6- and 30-year duration for infants, children and adults, respectively, for 350 days per year.

  Current and future offsite adult, child and infant residents may also inhale dust from the site. Inhalation of dust in outdoor air by these potential receptors was evaluated following USEPA (2009a) RAGS Part F.

  Following ADEC (2010a) guidance, it was assumed that 70 kg adult residents consume 2 L/day of tapwater. Following USEPA (1989) guidance, it was assumed that 15 kg child residents consume 1 L/day of tapwater. Infants were assumed to weigh an average of 6.75 kg (the average of the age-group specific mean values from 0 to 1 year) and to consume 1.05 L/day (the time-weighted average of the *per capita* age-group-specific 95^{th} percentile values from 0 to 1 year) of tapwater based on USEPA (2011a) guidance. The groundwater ingestion exposure parameters for infants likely overestimate potential exposure because it was assumed that they do not breastfeed and do not consume formula made with distilled water (a typical pediatric guideline for the first several months of life).

Fractions of homegrown fruit and vegetables ingested, water-to-produce BCFs and ingestion rates for offsite adult and child residents for the ARCADIS Comparative Scenario are discussed in Section 4.1.3.1.6.

- **Current and future offsite indoor and outdoor commercial/industrial workers** were considered to be individuals from 18 to 65 years old. It was assumed that these potential receptors perform commercial and/or industrial work activities indoors or outdoors at offsite locations under current or future land use scenarios during a standard 40-hour work week for 25 years, for 250 days per year. These receptors may ingest sulfolane in groundwater as tapwater. Following ADEC (2010a) guidance, it was assumed that 70 kg offsite adult commercial/industrial workers consume 2 L/day of tapwater. In addition, they may inhale dust that may have been released onsite via wind erosion. Potential exposures to COPCs in dust were considered to be insignificant for offsite indoor commercial/industrial workers. Inhalation of dust in outdoor air by outdoor commercial/industrial workers was evaluated following USEPA (2009a) RAGS Part F.

- **Current and future offsite recreational users.** Sulfolane may potentially migrate offsite via groundwater to surface water and to sediment in downgradient surface-water bodies. Access to downgradient, offsite surface-water bodies is minimal due to surrounding industrial land use and hazardous physical conditions, and direct contact with surface water and sediment by human receptors is limited. Regardless, for this HHRA, ingestion of surface water by offsite adult and child recreational users while swimming is considered a potentially complete exposure pathway. Recreational user exposure assumptions for the ARCADIS Comparative scenario are discussed in Section 4.1.3.3.

- **Current and future offsite construction/trench workers** were considered to be individuals from 18 to 65 years old. These receptors were assumed to perform short-term maintenance and emergency repair activities on underground utilities at offsite properties. These potential receptors may be exposed to sulfolane in groundwater that has pooled in a trench during performance of the maintenance and/or repair task. It was assumed that offsite construction/trench workers incidentally ingest 0.0037 L/day of groundwater pooled in a trench. This rate is based on the mean ingestion rate for wading/splashing presented in the USEPA (2011a) EFH Table 3-93 (3.7 milliliters per hour * 1 hour per day). This consumption rate is conservative, because dewatering usually occurs at excavation sites where water has pooled in trenches. It was conservatively assumed that the same worker performs multiple maintenance and/or repair tasks. These potential receptors (70 kg for adults) may be exposed to sulfolane in groundwater for 1 hour each day of a standard 5-day work week, for 125 days per year, for 1 year.

4.1.1.4 Exposure Pathway Evaluation.

Potential exposure pathways selected for quantitative evaluation are shown in the on- and offsite human health CSMs. An exposure pathway was retained for further evaluation if it was considered potentially complete. Each of the following components must be present in order for an exposure pathway to be considered complete (USEPA 1989):

- Source and/or constituent release mechanism
- Retention or transport medium
- Receptor at a point of potential exposure
- Exposure route at the exposure point.

Complete exposure pathways were evaluated for identified COPCs. Only potential ingestion exposures were quantitatively assessed for sulfolane. Dermal contact and inhalation exposure routes are not significant for sulfolane. The ATSDR (2010 and 2011) Health Consultations support these conclusions. Animal studies have shown that sulfolane is not readily absorbed through human skin because of its low permeability (Brown et al. 1966) and is not expected to pose a significant risk via an inhalation exposure route due to its low volatility (Andersen et al. 1977). Brown et al. (1966) studied the skin and eye irritant and skin sensitizing properties of acute exposures to sulfolane on two animal species. This study concluded that sulfolane did not irritate or sensitize the skins of guinea pigs or rabbits and, undiluted, was only very mildly irritating on the eyes of rabbits.

Andersen et al. (1977) conducted acute and subacute investigations of the inhalation toxicity of sulfolane on four animal species including monkey, dog, guinea pig and rat. A no-observed-effect level for sulfolane of 20 mg/m^3 was reported, and the authors concluded that airborne concentrations of sulfolane as high as those investigated are unlikely to be encountered on any but an emergency basis. Andersen et al. (1977) reported that sulfolane has a relatively low vapor pressure (approximately 0.13 millimeter of mercury at 32 °C and only unusual conditions would produce an extensive release of aerosolized sulfolane. Andersen et al. (1977) further noted that if sulfolane is handled at room temperature in an area with proper ventilation, it should not be regarded as posing an unusual hazard.

Potentially complete and significant exposure pathways were identified for the following receptors, with the exception that dermal and inhalation exposures to sulfolane are incomplete (as noted above):

- Onsite indoor commercial/industrial worker (current and future):
  - Inhalation of volatile COPC vapors in indoor air from groundwater.
- Onsite outdoor commercial/industrial worker (current and future):

  - Ingestion of, dermal contact with and inhalation (particulates) of COPCs in surface soil.
  - Dermal contact with COPCs in groundwater while extinguishing fires was qualitatively evaluated.
  - Inhalation of volatile COPC vapors in outdoor air volatilized from surface and subsurface soil and groundwater.

- Onsite construction/trench worker (current and future):
  - Ingestion of, dermal contact with and inhalation (particulates) of COPCs in surface and subsurface soil.
  - Inhalation of volatile COPC vapors in trench air from surface and subsurface soil and groundwater.
  - Ingestion of and dermal contact with COPCs in groundwater in excavation trenches.
- Onsite adult visitor (current and future):
  - Inhalation of volatile COPC vapors in indoor air from groundwater.
- Offsite adult, child and infant residents (current and future):
  - Ingestion of sulfolane in groundwater (i.e., tapwater).
  - Ingestion of homegrown produce irrigated with sulfolane-impacted groundwater.
  - Inhalation of fugitive windborne dust from onsite COPCs in surface soil.
- Offsite indoor and outdoor commercial/industrial worker (current and future):
  - Ingestion of sulfolane in groundwater (i.e., tapwater).
  - Inhalation of fugitive windborne dust from onsite COPCs in surface soil (outdoor worker only).
- Offsite construction/trench worker (current and future):
  - Ingestion of sulfolane in groundwater (i.e., in excavation trenches).
- Offsite adult and child recreational users (current and future):

- Ingestion of sulfolane in surface water (i.e., pore water).

4.1.2 Data Evaluation, Constituent of Potential Concern Selection and Identification of Data Gaps

The proposed methods for data evaluation, identification of data gaps, selection of COPCs and proposed sampling to address data gaps are discussed below. Both maximum and 95% UCL on the mean constituent concentrations for groundwater were evaluated.

4.1.2.1 Data Evaluation

The available data that were used include analytical results from soil investigations conducted at the site since 2001. Data from four sets of soil samples were evaluated, including samples collected in March and May 2001, July 2004, October 2010 and October 2011. One soil sample collected in 2010 (O-2 [7.5-9]) was determined to be unusable in a Level four data validation, so this sample was not included in EPC calculations.

Groundwater and surface-water data collected during the last two years were also included. SWI provided the soil and groundwater analytical data used in the HHRA in an electronic format. Initially, the data were separated into individual datasets by environmental media, including: onsite groundwater, offsite (downgradient) groundwater, onsite surface soil (0 to 2 feet bgs) and onsite subsurface soil (2 to 15 feet bgs).

The quality of the data is acceptable for risk assessment use. Parameters evaluated in the data quality assessment include spatial and vertical coverage and representativeness of sampling locations, analytical methods and reporting limits used by the laboratories, and data qualifiers applied during data validation. The HHRA relies on validated data supplied by SWI as presented in the Revised Site Characterization Report (Barr 2012). Data collected for this evaluation were collected per ADEC-approved sampling and analysis plans. Consideration was given to the recently developed standard procedure for analyzing sulfolane in groundwater (isotope dilution) and the historical variability between analytical results. The data relied upon in this risk assessment met the following criteria for data usability for risk assessment as recommended in ADEC (2010a) guidance:

- Analytical data sufficient for adequate site characterization were available.
- Data were collected consistent with ADEC and USEPA guidance.
- Sampling and analytical procedures gave accurate constituent-specific concentrations.

- Level two data validation was performed on analytical laboratory data used for this evaluation. Validation reports for the 2011 soil and groundwater data, and for the 2012 pore-water data prepared by SWI, were included in the Revised Site Characterization Report (Barr 2012). Level four data validation was performed on the 2010 sulfolane in soil analyses.

- Method detection limits and sample quantitation limits were below screening criteria.

- Qualified data were used in the risk assessment; potential bias from qualified data and how it might result in an over or under estimation of risk is discussed in Section 4.5.

- Rejected data were not used for risk assessment purposes.

- For a given well, if all samples were reported as non-detects, then the lowest detection limit associated with any sampling event at that well was used to represent the well.

- If a well had both detected concentrations and reported non-detects for a given COPC, then the non-detect was represented by a value equal to one-half the detection limit associated with that COPC in that sampling event.

Offsite groundwater has been sampled at monitoring wells and private residential wells. At the request of ADEC, the off-site area was delineated into smaller EUs for the purposes of the 95% UCL evaluation. Accordingly, ARCADIS developed three separate EUs (e.g., EU-1, EU-2 and EU-3) for statistical evaluation. These EUs were based on estimated sulfolane isocontour lines developed from fourth quarter 2011 groundwater sampling data, and generally reflect spatially contiguous areas that represent certain ranges of concentration and portions of the sulfolane plume in groundwater. Some data points outside of the concentration range are present within each of the defined EUs and are the result of data collected from well screens of varying depths. These data points were included in the analysis, because it is reasonable to assume that any hypothetical exposures to water from drinking water wells within any given unit may also include exposures to groundwater generated at varying depths. The EUs are bounded by the concentration contours of greater than (>) 100 µg/L, >25 µg/L and detectable sulfolane (Figure 3-3). These contour intervals were selected and drawn using the combined offsite well data set and are based on best professional judgment. Guidance presented in the Data Quality Assessment: Statistical Methods for Practitioners (USEPA 2006a) was considered during selection of the off-site groundwater dataset(s). The data from wells within a given EU were used to estimate the 95% UCL on the mean concentration as a health-protective and representative EPC. ProUCL version 4.1 (USEPA 2011b) was used to derive the 95% UCL on the mean of the constituent concentrations.

The utility of the soil and groundwater analytical data identified in the SWI (2000 and 2001) contaminant characterization studies conducted for the site was evaluated for the HHRA. The characterization study

conducted at the site in 2001 was performed to collect additional soil and groundwater data to address data gaps from the site investigation conducted in 2000. In general, for both media, the analytical methods used included those for GRO, DRO, RRO, BTEX, selected metals, VOCs, SVOCs and sulfolane (for groundwater only).

4.1.2.2 Constituents of Potential Concern

COPCs have been identified from a list of potential COIs, such as those that were likely used or spilled at the site. COPCs for each dataset were carried through the HHRA process.

Preliminary lists of COIs and COPCs in soil and groundwater at the site were presented in the Site Characterization and First Quarter 2011 Groundwater Monitoring Report (Barr 2011). The lists were revised in the Addendum (ARCADIS 2011b) based on the ADEC (2011a) Comment Matrix on the site characterization report. The lists of preliminary COIs and COPCs were also presented in the RAWP (ARCADIS 2011a).

As noted in the RAWP (ARCADIS 2011a), the list of COIs was developed according to the following process:

1. FHRA compiled a list of spills based on staff interviews, refinery records and a review of spill records retained by the ADEC.

2. The list of spills was refined by eliminating:

    a. Spills less than 10 gallons.
    b. Spills that were reportedly contained.
    c. Spills that were remediated and had confirmation sampling.

For many spills on the list, the material spilled was specific to one ingredient (e.g., propylene glycol) or was a material with obvious and limited ingredients (e.g., kerosene). However, the individual ingredients (e.g., oily water) of the other materials reportedly spilled were not provided. Refinery specialists such as chemists, wastewater experts and production leads were consulted to apply operational knowledge of the refinery to determine the ingredients that made up this set of materials. By this process, the list of spills was then distilled down to the “ingredients” or the primary constituents that make up the material spilled. This ingredient list was also compared to constituents that had been included in laboratory analyses of facility wastewater. The resulting ingredient list was then used to make up a list of COIs for the site. The COI list also included constituents that were analyzed during previous site characterization studies, regardless of whether they were detected above the PQL. The list of COIs for the site is shown in Table 3-1. Constituents in the ingredient list that were analyzed for but not detected were not removed from this list. If a constituent was previously detected at the site and/or was included in the ingredient list, it was considered a COI.

Table 3-1 indicates if a constituent was previously analyzed in soil or groundwater samples collected at the site. Table 3-1 also indicates if a constituent was included in the ingredient list; the last four columns of the table summarize whether toxicity data are available from the IRIS (USEPA 2012a).

For this Revised Draft Final HHRA, maximum detected concentrations and/or the laboratory reporting limits of COIs in soil and groundwater are compared with ADEC screening levels corresponding to a 1×10^{-6} target ELCR and 0.1 target HQ, as shown in Table 3-2a. COI soil concentrations were compared with ADEC screening levels protective of potential migration to groundwater based on a zone with less than 40 inches of annual precipitation, direct-contact exposures and outdoor inhalation (ADEC 2008a [Table B-1 of 18 AAC 75, Method Two]). If ADEC soil screening levels were unavailable, then COI concentrations in soil were compared with USEPA RSLs (USEPA 2011c), adjusted to a target ELCR of 1×10^{-6} (if necessary) and a HQ equal to 0.1, for the applicable exposure pathway. Soil screening levels for GRO, DRO and RRO were from ADEC (2008a) Table B-2 Method Two. COI groundwater concentrations were compared with ADEC groundwater screening levels (ADEC 2008a; Table C). If ADEC groundwater screening levels were unavailable, then COI concentrations were compared with USEPA RSLs (USEPA 2011c) based on tapwater ingestion.

The higher of either the maximum COI concentration detected above the laboratory reporting limit or maximum detection limit was compared with the selected ADEC screening levels. The selected soil screening levels were based on the lesser of the migration to groundwater, $^1/_{10}$ the direct contact or $^1/_{10}$ the outdoor air screening levels. COIs with concentrations exceeding the selected soil screening level were identified as COPCs. Table 3-2a lists the COPCs identified in soil and groundwater based on ADEC (2010a) COPC selection guidance applied to the COIs identified in Table 3-1.

The preliminary COPCs identified at the site, as presented in Table 3-2a, are COIs that were detected in site media and exceeded ADEC screening levels. COIs not detected in site media but that had practical quantitation limits exceeding ADEC screening levels and COIs identified by the refinery as ingredients that could have been released are also considered COPCs. Arsenic was eliminated as a COPC in groundwater based on published background concentrations for the area of the site (U.S. Geological Survey 2001). However, it was retained as a COPC in soil in the RAWP (ARCADIS 2011a). An evaluation of the 2011 arsenic in soil data was presented in the Revised Site Characterization Report (Barr 2012). Based on this evaluation, it is likely that the presence of detectable arsenic in soil samples collected at the site is attributable to background concentrations. No other metal COIs were eliminated from the list of COPCs based on background concentrations. In accordance with ADEC (2010a) guidance, Table 3-2a has been provided to the ADEC in Microsoft® Excel format.

Table 3-2b summarizes COPCs by environmental media.

4.1.2.3 Data Gaps

Based on a review of the preliminary human health CSMs and available analytical data for environmental samples collected at the site, and discussions held during the June 24, 2011 Risk Assessment Scoping Meeting, four potential risk assessment data gaps were indicated:

- Limited surface soil data were available for the evaluation of potential risks and hazards to onsite human receptors.
- Onsite containment of COPCs other than sulfolane must be supported.
- Possible connection between groundwater at the site and surface water must be determined.
- No soil gas data were available to evaluate onsite vapor intrusion concerns.

4.1.2.4 Sampling Plans to Address Data Gaps

Sampling plans for additional data collection are described in the Addendum (ARCADIS 2011b). With respect to risk assessment data gaps identified in Section 3.1.2.3, the following field activities have been conducted:

- Onsite soil assessment activities, to characterize soil impacts and provide data for risk assessment activities. The soil data collected in 2011 adequately characterized the nature and extent of surface and subsurface impacts for the purposes of this HHRA evaluation. Additional sampling is planned for 2012 to complete characterization for the purposes of a remediation feasibility study. The 2011 soil data were validated and included in this evaluation.
- Additional groundwater sampling, during the third and fourth quarters 2011, confirmed that no other COPCs (except sulfolane) have migrated offsite.
- A pore-water investigation was conducted to better characterize sulfolane concentrations in the groundwater/surface-water interface and the potential for surface-water sulfolane impacts. The March 2012 samples were collected when the adjacent surface-water body was frozen; therefore, the degree of connectivity with surface water, if any, could not be established. Therefore, the piezometer samples were likely more representative of groundwater. Because sulfolane degrades more rapidly in the presence of nutrients and oxygen that would be present in the surface water (ADHSS 2010), and given the limited groundwater-surface water interchange adjacent to a frozen surface-water body, the groundwater collected adjacent to two of the three surface-water bodies in 2012 likely overestimates the

surface water concentrations at those locations. The data presented in this Revised Draft Final HHRA provide a health-protective estimate of risk to swimmers.

Soil gas data were not collected to evaluate potential vapor intrusion concerns. Instead, onsite groundwater data were used to evaluate the vapor intrusion exposure pathway. All onsite groundwater analytical data collected during the last 2 years (2009 through 2011) were used to predict indoor air concentrations of volatile COPCs and to estimate risks and hazards to current and future onsite indoor commercial workers. The maximum detected groundwater concentration for each COPC was used as the source term for J&E groundwater-to-indoor air modeling (USEPA 2004b) in the maximum exposure scenario. The 95% UCL concentration calculated from the average concentration in each onsite well was used as the source term in the 95% UCL scenario.

4.1.3 Quantification of Exposure

The objective of the exposure assessment was to estimate the type and magnitude of potential receptor exposure to COPCs. Results of the exposure assessment were then combined with constituent-specific toxicity values in the toxicity assessment (see Section 4.2) to characterize potential risks (USEPA 1989).

4.1.3.1 Dose/Intake Equations

Exposures were quantified using standard exposure equations consistent with RAGS (USEPA 1989, 1991, 2004a and 2009a) for the potentially complete exposure pathways identified in Section 4.1.1.4.

The general algorithms presented below were used to estimate the LADD for carcinogenic compounds and the ADD for noncarcinogenic COPCs for direct-contact pathways (i.e., ingestion and dermal contact) by combining environmental media concentrations with the receptor-specific exposure parameters that constitute "intake factors." Both the ADD and the LADD are in units of mg/kg-day (USEPA 1989). For inhalation exposure pathways, exposure was estimated as an AEC for noncarcinogenic COPCs or LAEC for carcinogenic COPCs. Both the AEC and the LAEC are in units of mg/m^3 (USEPA 2009a).

The dose equations and parameter descriptions used are provided in the following subsections.

4.1.3.1.1 Incidental Ingestion of Soil

The doses of COPCs associated with incidental ingestion of soil were calculated as follows:

$$\text{Dose} = \frac{EPC_s * IR_s * FI * EF * ED * CF}{} * RAF$$

$$\text{BW} * \text{AT}$$

Where:

Dose = ADD or LADD (mg/kg-day)

EPC_s = EPC in soil (mg/kg)

IR_s = soil ingestion rate (milligrams soil per day)

FI = fraction ingested (unitless)

EF = exposure frequency (days per year)

ED = exposure duration (years)

CF = conversion factor ($1x10^{-6}$ kg/mg)

BW = body weight (kg)

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

RAF = relative absorption factor (unitless), assumed to equal 1

The USEPA (1989) defines FI as a "pathway-specific" value that should be applied to consider constituent location and population activity patterns. FI accounts for the fraction of the site covered with asphalt or vegetation, which reduces potential exposure. Following the ADEC's (2010a) guidance, an FI of 1 was assumed for the current and future onsite outdoor commercial/industrial worker and future onsite construction/trench worker to provide a health-protective estimate of risk.

4.1.3.1.2 Dermal Contact with Soil

Absorbed doses of constituents associated with dermal contact with soil were calculated as follows:

$$\text{Dose} = \frac{EPC_s * SSA_s * AF * FC * ABS_d * EV_s * EF * ED * CF}{\text{BW} * \text{AT}}$$

Where:

Dose = ADD or LADD (mg/kg-day)

EPC_s = EPC in soil (mg/kg)

SSA_s = SSA available for contact (cm^2/event)

AF = soil-to-skin adherence factor (mg/cm^2-event)

FC = fraction in contact with soil (unitless)

ABS_d = dermal absorption factor (unitless)

EV_s = event frequency (soil) (events/day), assumed to be 1 per day unless otherwise noted

EF = exposure frequency (days/year)

ED = exposure duration (years)

CF = conversion factor ($1x10^{-6}$ kg/mg)

BW = body weight (kg)

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

Constituent-specific dermal parameters, such as SSA_s, AF and ABS_d were provided from USEPA (2004a) RAGS Part E. ABS_d are presented in Table 3-13.

Similar to FI for the soil ingestion pathway, FC was added to the dermal contact equation to account for the fraction of the site covered with asphalt or vegetation, which reduces potential exposure. Following the ADEC's (2010a) guidance, an FC of 1 was assumed for the current and future onsite commercial/industrial worker and future onsite construction/trench worker to provide a health-protective estimate of risk.

4.1.3.1.3 Ingestion of Groundwater

The doses of COPCs associated with ingestion of groundwater were calculated as follows:

$$\text{Dose} = \frac{EPC_w * IR_w * EF * ED}{BW * AT}$$

Where:

Dose = ADD or LADD (mg/kg-day)

EPC_w = EPC in water (mg/L)

IR_w = water ingestion rate (liters water/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight (kg)

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

4.1.3.1.4 Dermal Contact with Groundwater

Absorbed doses of constituents associated with dermal contact with groundwater were calculated as follows:

$$\text{Dose} = \frac{DA_{event} * SSA_w * EV_w * EF * ED}{BW * AT}$$

Where for organics ($t_{event} \leq t^*$):

$$DA_{event} = 2 * FA * K_p * EPC_w * CF * \sqrt{\frac{6 * \tau_{event} * t_{event}}{\pi}}$$

Where for organics ($t_{event} > t^*$):

$$DA_{event} = FA * K_p * EPC_w * CF * \left[\left(\frac{t_{event}}{(1+B)}\right) + \left(2\tau_{event}\left[\frac{1+3B+3B^2}{(1+B)^2}\right]\right)\right]$$

Where for inorganics:

$$DA_{event} = K_p * EPC_w * CF * t_{event}$$

Dose = ADD or LADD (mg/kg-day)

DA_{event} = dose per event (mg/cm^2-event)

SSA_w = SSA available for contact with water (cm^2/event)

EV_w = event frequency (water) (events/day), assumed to be 1 per day unless otherwise noted

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight (kg)

t* = time to reach steady state (hours), equivalent to 2.4 x τ_{event}

AT = averaging time (days), for carcinogens is equal to 70 years * 365 days per year, and for noncarcinogens is equal to ED * 365 days per year

FA = fraction absorbed (unitless)

K_p = permeability coefficient (centimeter/hour)

EPC_w = EPC in water (mg/L)

CF = conversion factor (1x10^{-3} liters per cubic centimeter)

T_{event} = lag time per event (hours/event)

B = permeability ratio (unitless)

t_{event} = event duration (hours/event)

4.1.3.1.5 Inhalation of Outdoor or Indoor Air

Exposure concentrations associated with the inhalation of vapors or particulates in outdoor or indoor air are calculated using USEPA (2009a) RAGS Part F methodology as follows:

$$\text{AEC or LAEC} = \frac{EPC_a * EF * ED * ET}{AT}$$

Where:

AEC or LAEC = average or lifetime exposure concentration in air ($\mu g/m^3$)

EPC_a = EPC in outdoor or indoor air ($\mu g/m^3$)

EF = exposure frequency (days/year)

ED = exposure duration (years)

ET = exposure time (hours/day)

AT = averaging time (hours), for carcinogens is equal to 70 years * 365 days per year * 24 hours per day, and for noncarcinogens AT is equal to ED (in years) * 365 days per year * 24 hours per day

4.1.3.1.6 Ingestion of Homegrown Produce

Groundwater from the site may be used to irrigate locally grown crops, creating the potential for sulfolane to be taken up into plants that are then consumed by humans. In the few studies that have been conducted on the topic of uptake in plants, sulfolane has been demonstrated to be taken up into plants as the result of the constituent's high miscibility with water. Sulfolane is carried, along with water, through the roots, into the xylem and ultimately into the leaves of the plants. When water is lost through the leaves due to evapotranspiration, the sulfolane, due to its low volatility, tends to remain in the leaves where it may accumulate. Based on this information, it is assumed that if sulfolane is taken up by plants, it would predominantly be present in the leaves rather than in the roots or fruit.

This assumption is corroborated by the Final Results of the North Pole Garden Sampling Project (ADEC 2011b), which demonstrated that concentrations in roots were substantially lower than those in the stems and leaves. In the ADEC (2011b) study, which was led by ADHSS, 27 types of plant parts from multiple gardens irrigated with sulfolane-containing groundwater were collected from July to September 2010. Approximately one-half of the plant samples were reported as not detected, but 14 of the plant types tested were confirmed to contain sulfolane, primarily in the leaves and stems. Using data from the Final Results of the North Pole Garden Sampling Project (ADEC 2011b), the ADHSS evaluated the potential for risk to consumers of vegetables irrigated with sulfolane-containing water and concluded that sulfolane levels in the plants were low and not likely to cause any adverse health effects. However, because of the limited number of gardens sampled and the fact that the data were collected during only one growing season, the results of the investigation were considered preliminary and the exposure pathway was further evaluated in this assessment.

Following USEPA (2005) guidance, bioaccumulation of sulfolane in locally grown crops was evaluated using a biotransfer factor to estimate concentrations in plant tissues based on groundwater concentrations. There are no accepted values developed for sulfolane, but there is evidence to suggest that the uptake of sulfolane does not follow standard models based on partitioning coefficients (e.g., K_{ow}); therefore, an appropriate surrogate was not identified. Given the lack of constituent-specific information available in the literature, the ADEC has requested use of a factor of 1. Use of this value assumes that the concentration of sulfolane in the edible portions of the plant tissues is equivalent to the concentration of sulfolane in groundwater. To allow a direct risk comparison between this and the PPRTV Scenario, with only the toxicity criteria differing, ARCADIS has adopted this BCF for the purposes of this scenario.

After estimating the EPC, the doses of sulfolane associated with resident ingestion of homegrown fruits and vegetables were calculated using the following equation:

$$\text{Dose} = \frac{EPC_p * (IRP_{fr} + IRP_{vg}) * FI * EF * ED * CF}{BW * AT}$$

Where:

Dose = ADD (mg/kg-day)

EPC_p = EPC in produce (mg/kg) = EPC_w * BCF

Where:

EPC_w = EPC in water (mg/L)

BCF = water-to-produce bioconcentration factor (unitless)

IRP_{fr} = fruit ingestion rate (mg/day)

IRP_{vg} = vegetable ingestion rate (mg/day)

FI = fraction ingested (unitless)

EF = exposure frequency (days/year)

ED = exposure duration (years)

CF = conversion factor ($1x10^{-6}$ kg/mg)

BW = body weight (kg)

AT = for the noncarcinogen sulfolane is equal to ED * 365 days per year

For the ARCADIS Comparative Scenario, the same produce consumption rates described for the PPRTV Scenario (Table 3-12) were used.

4.1.3.1.7 Ingestion of Surface Water

The doses of sulfolane associated with ingestion of surface water while swimming were calculated as follows:

$$\text{Dose} = \frac{EPC_w * ET * EF * ED * CR_w}{BW * AT}$$

Where:

Dose = ADD (mg/kg-day)

EPC_w = EPC in water (mg/L)

ET = exposure time (hours per day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

CR_w = contact rate of surface water (liters/hour)

BW = body weight (kg)

AT = for the noncarcinogen sulfolane is equal to ED * 365 days per year

For this Scenario, as shown in Table 3-12, the offsite adult and child recreational user surface-water ingestion rates of 0.071 and 0.12 liter/hour, respectively, were based on the upper percentile values for swimmers presented in the USEPA (2011a) EFH Table 3-5 representing the maximum ingestion rate for adults and the 97th percentile ingestion rate for children age 18 and under. Adult and child recreational users were assumed to swim for 30 and 6 years, respectively, for 60 days per year for 1 hour per day.

4.1.3.2 Exposure Point Concentrations

Per ADEC (2010a) guidance, “the exposure point concentration is used to assess risk and should be estimated using a 95% UCL on the mean of the contaminant concentrations.” The EPC represents the average concentration of a COPC in an environmental medium that is potentially contacted by a receptor during the exposure period (USEPA 1989). The USEPA (1989) also recommends the use of the 95%

UCL as a conservative estimate of the EPC, because it represents the average concentration for which we have 95 percent confidence that the true mean concentration has not been exceeded. Unless there is site-specific evidence to the contrary, an individual receptor is assumed to be equally exposed to media within all portions of the EU during the time of the risk assessment (USEPA 2002c). For this HHRA ADEC has also requested evaluation of maximum COPC concentrations in groundwater as EPCs in the ARCADIS Comparative Scenario. Note that the ADEC Draft Risk Assessment Procedures Manual was updated during preparation of this HHRA (ADEC 2011c). The updated manual includes guidance on the use of maximum groundwater concentrations for EPCs. Because groundwater data collected from off-site wells indicate that offsite sulfolane concentrations are generally not increasing, the use of the maximum concentration will overestimate the true risk for most, actual receptors.

EPCs are estimated separately for each medium. Consistent with USEPA (2006b, 2007) guidance, surface soil, subsurface soil and groundwater EPCs were estimated using the 95% UCL of the mean for datasets with at least eight samples and at least five detected values. For this HHRA, a "dataset" was considered the aggregate of samples for one COPC, for one pathway, within a particular EU (onsite or offsite). Calculation of a 95% UCL depends on the distribution of the dataset and variability in the data. To assess statistical validity, data evaluation, distribution testing and 95% UCL calculations were performed using the USEPA's ProUCL version 4.1 (http://www.epa.gov/osp/hstl/tsc/software.htm) and according to the recommendations provided in the associated technical documentation (USEPA 2006, 2007, 2011b). Analytical data used for the HHRA are provided in Appendix A and ProUCL output files are included in Appendix B. For datasets with fewer than eight samples or fewer than five detected values, the EPC was the maximum detected concentration. Soil and groundwater datasets for most COPCs have more than eight samples each.

To combine data collected from monitoring wells and private residential wells, individual well means were calculated. The following methods were used to normalize the groundwater data in a manner that provides equal representation between wells with different numbers of observations:

- For a given well, if all samples were reported as non-detects, then the lowest detection limit associated with any sampling event at that well was used to represent the well.

- If a well had both detected concentrations and reported non-detects for a given COPC, then any non-detect was represented as one-half the detection limit associated with that sampling event for that COPC.

With the individual well means calculated as described above, ProUCL was used to estimate the 95% UCL of the mean of sulfolane across all wells in an EU (Figure 3-3). EU-1 represents approximate sulfolane concentrations in groundwater of $\geq$100 µg/L, EU-2 where detected sulfolane concentrations range from $\geq$25 to 99.9 µg/L, and EU-3 where sulfolane was from not detected above the laboratory reporting limit to 24.9 µg/L. Given the sizable area of each EU, some results included in the data analyses are different from

others in each EU. For example, some non-detect results occur in EU-1 and EU-3. These values are primarily attributable to groundwater samples collected from variable screen depths. It is reasonable to assume that groundwater extracted from a variety of screen lengths may be ingested by potential receptors that might use groundwater as drinking water. Therefore, these data points were included in the EPC calculations for each EU. Non-detect observations for the COPCs in soil and groundwater were addressed using the methods described above.

In addition, per ADEC (2010a) guidance for duplicate samples, the highest detected value from the primary and duplicate samples was used to represent that sample result. For any COPC, if the 95% UCL COPC of the mean concentration exceeded the maximum detected concentration, then the maximum detected concentration was the EPC. Summary statistics for the COPCs are presented in the risk characterization, including detection frequency, number of samples, minimum and maximum detected concentrations, and calculated 95% UCL concentrations.

The same EPCs used for the PPRTV scenario (Tables 3-3 through 3-10) were used in the ARCADIS Comparative Scenario. EPCs were estimated separately for each exposure medium:

- Surface soil (0 to 2 feet bgs; see Table 3-3 for 95% UCL COPC concentrations
- Subsurface soil (0 to 15 feet bgs; see Table 3-4a for maximum COPC concentrations and Table 3-4b for 95% UCL COPC Concentrations Onsite groundwater (see Table 3-5a for maximum COPC concentrations Table 3-5b for 95% UCL COPC Concentrations
- Offsite groundwater in all wells (see Table 3-6 for maximum sulfolane concentration)
- Offsite groundwater in EU-1 (see Table 3-7 for 95% UCL sulfolane concentration)
- Offsite groundwater in EU-2 (see Table 3-8a for maximum sulfolane concentration Table 3-8b for 95% UCL sulfolane concentration)
- Offsite groundwater in EU-3 (see Table 3-9a for maximum sulfolane concentration Table 3-9b for 95% UCL sulfolane concentration)
- Offsite surface water (see Table 3-10 for maximum sulfolane concentration from pore water).

Soil, groundwater, outdoor air, indoor air, homegrown produce and surface-water EPCs are further discussed below.

4.1.3.2.1 Soil Exposure Point Concentrations

Onsite receptors may potentially contact surface soil or a combination of surface and subsurface soil. According to ADEC guidance 18 AAC 75.340(j)(2), "human exposure from ingestion, direct contact or inhalation of a volatile substance must be attained in the surface soil and the subsurface soil to a depth of at least 15 feet, unless an institutional control or site conditions prevent human exposure to the subsurface" (ADEC 2008c). Currently and in the future, FHRA will have institutional controls in place (i.e., permits) that provide worker protection (i.e., appropriate personal protective equipment) in the event of planned excavation of onsite soil. For this HHRA, two soil EPCs are calculated for each COPC. Surface soil is considered to occur from 0 to 2 feet bgs (Table 3-3) and subsurface soil is considered to occur from 0 to 15 feet bgs (Tables 3-4a and 3-4b). EPCs for soil were calculated using the 95% UCL on the mean of the dataset for surface soil exposures, or the maximum detected COPC concentrations for surface and subsurface soil exposures (relevant to potential onsite construction/trench workers).

4.1.3.2.1.1 Surface Soil Exposure Point Concentrations

For this HHRA, it is presumed that onsite commercial/industrial workers may potentially contact surface soil onsite that is not covered with pavement or vegetation. Therefore, surface soil EPCs were calculated and used to evaluate potential exposure by onsite commercial/industrial workers, using analytical data from the surface soil dataset in uncovered portions of the site (i.e., soil samples collected from ground surface to 2 feet bgs). The 95% UCL of the mean concentrations of COPCs in surface soil collected from 0 to 2 feet bgs were used to evaluate:

- Direct-contact exposure pathways to onsite outdoor commercial/industrial workers
- Potential inhalation of fugitive windborne dust from onsite surface soil by onsite outdoor commercial/ industrial workers, offsite residents and offsite outdoor commercial/industrial workers.

4.1.3.2.1.2 Surface and Subsurface Soil Exposure Point Concentrations

The 95% UCL of the mean concentrations of surface soil collected from 0 to 2 feet bgs were used to evaluate direct-contact exposure pathways to onsite outdoor commercial/industrial workers, and potential inhalation of fugitive windborne dust from onsite soil by onsite and offsite outdoor commercial/industrial workers. The onsite construction/trench worker may be directly exposed to surface and subsurface soil during excavation activities. Therefore, EPCs for evaluating exposure by the onsite construction/trench worker were generated using analytical data from the combined surface and subsurface soil dataset (i.e., soil samples collected from ground surface to as deep as 15 feet bgs). The maximum detected concentrations in the combined surface and subsurface soil sample dataset were used to estimate surface and subsurface soil EPCs for direct-contact pathways for the onsite construction/trench worker because that exposure may be localized rather than averaged over the entire site. In addition, in

accordance with ADEC guidance (2010a), surface and subsurface soil EPCs based on the 95% UCLs were also used to evaluate potential exposures by the construction/trench worker.

4.1.3.2.2 Groundwater Exposure Point Concentrations

For COPCs in groundwater, COPC EPCs were distinguished for both on- and offsite potential exposures as described in the following sections.

4.1.3.2.2.1 Onsite Groundwater Exposure Point Concentrations

Groundwater EPCs were used to estimate direct-contact exposure (i.e., dermal contact) by the onsite outdoor worker and incidental ingestion and dermal contact by onsite construction/trench workers during excavation activities. Groundwater COPC EPCs based on 95% UCL concentrations were estimated using the last 2 years of data (i.e., 2009 to 2011) collected from onsite groundwater monitoring wells. In addition to evaluating the potential exposures to COPCs in groundwater over an EU using 95% UCL concentrations, the ADEC also requested that groundwater EPCs be calculated using the maximum detected concentration during the last 2 years of groundwater monitoring (see Tables 3-5a and 3-5b).

4.1.3.2.2.2 Offsite Groundwater Exposure Point Concentrations

Offsite sulfolane groundwater EPCs were used to estimate direct-contact exposure (i.e., incidental ingestion) by offsite construction/trench workers during excavation activities and to estimate direct-contact exposure (i.e., ingestion) by offsite residents and commercial/industrial receptors. In addition to evaluating the potential exposures to sulfolane in groundwater using a 95% UCL concentration for each of the EUs depicted on Figure 3-3, the ADEC also requested risk calculations using the maximum detected sulfolane concentration during the last 2 years of groundwater monitoring (i.e., 2009 to 2011), applied to the entire offsite area. EPCs for the ARCADIS Comparative Scenario were derived for each offsite EU identified on Figure 3-3 including:

- All offsite wells (Table 3-6), evaluated using the maximum offsite concentration as the EPC
- EU-1 (Table 3-7), evaluated using the 95% UCL concentration in offsite wells in EU-1
- EU-2 (Table 3-8a for maximum concentrations and Table 3-8b for 95% UCL concentrations)
- EU-3 (Table 3-9a for maximum concentrations and Table 3-9b for 95% UCL concentrations.

In summary, the maximum detected concentrations of sulfolane in offsite groundwater from EU-1, EU-2 and EU-3 were used to estimate risks and hazards for relevant receptors for the ARCADIS Comparative

Scenario. In addition, for each EU, EPCs based on the 95% UCL were also used to estimate risks and hazards for relevant receptors at each of the offsite groundwater offsite EUs (EU-1, EU-2 and EU-3), per USEPA (1989) guidance and ARCADIS professional judgment.

4.1.3.2.3 Outdoor Air Exposure Point Concentrations

In accordance with the USEPA (1989), exposure to constituents in outdoor air was evaluated as exposure to fugitive dust emissions (for non-VOCs, from soil only) or volatile emissions (for VOCs, from soil or groundwater). The USEPA (2002b) recommendations for media transfer factors to evaluate these exposures are described below.

4.1.3.2.3.1 Estimating Outdoor Air Exposure Point Concentrations from Soil Concentrations

A PEF for non-volatile COPCs was used to estimate EPCs in outdoor air from soil. The industrial PEF (1.36×10^9 m^3/kg) obtained from the Supplemental Guidance for Developing Soil Screening Levels for Contaminated Sites (USEPA 2002b) was used to estimate outdoor air EPCs of non-volatile COPCs for onsite outdoor commercial/industrial workers and construction/trench workers potentially exposed to particulate emissions from soil.

A VF for VOCs was used to estimate EPCs of volatile COPCs in outdoor air from soil (VF_{soil}). Outdoor air EPCs were estimated for the onsite outdoor commercial/industrial worker and onsite construction/trench worker using the EPC for the combined surface and subsurface soil dataset. Constituent-specific VFs_{soil} were obtained from the USEPA (2011c) RSL spreadsheets, where they exist, to estimate outdoor air EPCs of volatile COPCs for onsite outdoor commercial/industrial workers and construction/trench workers potentially exposed to volatile COPCs emanating from surface and subsurface soil. For volatile COPCs not listed in the USEPA's RSL table, VFs were derived according to USEPA guidance (USEPA 2002b). If not otherwise obtained from RSL spreadsheets, the VFs used in this assessment are shown on Table 3-11.

The following equation was used to calculate outdoor air EPCs from soil EPCs using either a PEF or VF_{soil}:

$$EPC_a = \frac{EPC_s}{PEF \text{ or } VF_{soil}}$$

Where:

EPC_a = EPC in air (mg/m^3)

EPC_s = EPC in soil (mg/kg)

PEF = particulate emission factor (m^3/kg)

VF_{soil} = volatilization factor (soil) (m^3/kg)

4.1.3.2.3.2 Estimating Outdoor Air Exposure Point Concentrations from Groundwater Concentrations

Construction workers (i.e., trench workers) may also be exposed to VOCs released from shallow groundwater that may pool in a trench and volatilize to trench air. Groundwater occurs as shallow as 8 feet bgs in portions of the site. To estimate the potential concentrations of COPCs that could volatilize from groundwater to trench air, volatilization factors (VF_{gw}) obtained from the Virginia Department of Environmental Quality (2012) were used to estimate trench air EPCs from groundwater. The trench air EPCs were used to evaluate potential exposures by on and offsite construction/trench workers potentially exposed to volatile COPCs emanating directly from shallow groundwater in an excavation trench. The equation for using VF_{gw} to calculate trench air EPCs from groundwater EPCs is as follows:

$$EPC_a = EPC_{gw} * VF_{gw}$$

Where:

EPC_a = EPC in trench air (mg/m^3)

EPC_{gw} = EPC in groundwater (mg/L) (see Section 4.1.3.2.2 for discussion about on and offsite groundwater EPCs)

VF_{gw} = volatilization factor (groundwater) (liter per cubic meter)

For onsite exposures, the trench air EPCs are presented in Table 3-5a (maximum EPC) and Table 3-5b (95% UCL EPC). For offsite exposures, the trench air EPCs are presented in Tables 3-6 through 3-9b.

Onsite construction/trench workers may potentially be exposed to vapors emanating from soil during trench excavation. Therefore, potential exposures to volatile EPCs in trench air from both soil and shallow groundwater sources, as well as COPCs as fugitive dust from soil were estimated for onsite construction/trench workers. For offsite construction/trench workers, sulfolane in trench air from offsite groundwater is the only potential exposure onsite.

4.1.3.2.4 Indoor Air Exposure Point Concentrations

The Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (USEPA 2002a), Vapor Intrusion Pathway: A Practical Guide (ITRC 2007a) and Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios (ITRC 2007b) were used to assess vapor intrusion. The J&E model was used to estimate indoor air concentrations resulting from intrusion of vapors from sub-slab soil gas into onsite buildings. The J&E model is a one-dimensional, screening-level model used to evaluate subsurface vapor intrusion into buildings. It incorporates both convective and diffusive mechanisms to estimate the transport of constituent vapors emanating from soil gas into indoor spaces located directly above the source (J&E 1991, USEPA 2004b). When estimating the concentration of COPC vapors in indoor air, the J&E model assumes the following:

- Constant, infinite source of constituents (e.g., in groundwater or soil gas)
- Steady-state diffusion through the unsaturated zone
- Convective and diffusive transport through the basement floor or slab
- Complete mixing within the building, estimated using an air exchange rate.

Due to the uncertainties associated with partitioning from soil to soil gas, ITRC (2007b) does not recommend using soil data as a source of COPCs to evaluate potential vapor intrusion. Therefore, source concentrations were estimated using the groundwater data as discussed in Section 2.6.2. Source concentrations for the model consisted of the groundwater EPCs based on maximum detected COPC concentrations in groundwater as well as the 95% UCL of the mean groundwater concentrations (see Section 4.1.3.2.2). Site-specific parameters, such as soil type and average soil temperature, were used in the J&E model where available. The top 3 to 5 feet of soil was assumed to be sand. Geotechnical data show that this depth interval is silty sand. An average soil temperature of 5 °C was used. The remaining parameter values, including constituent-specific parameter values, were estimated using the default values provided by the USEPA (2004b) in the User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings and the associated model spreadsheets. Appendix C presents the results of the USEPA's J&E-based model to predict indoor air COPC concentrations from COPC concentrations in onsite groundwater. For onsite exposures, the indoor air EPCs are presented in Table 3-5a (maximum EPC) and Table 3-5b (95% UCL EPC). For offsite exposures, the indoor air EPCs are presented in Tables 3-6 through 3-9b.

4.1.3.2.5 Homegrown Produce Exposure Point Concentrations

Residents who consume homegrown produce that has been irrigated with offsite groundwater were evaluated. Homegrown produce EPCs were calculated using BCFs applied to offsite groundwater EPCs (Tables 3-6 through 3-9b). The Final Results of the North Pole Garden Sampling Project (ADEC 2011b) showed that sulfolane was taken up into garden plants at concentrations below adult risk-based screening criterion developed by the ADHSS. However, a BCF equal to 1 was used predict uptake of sulfolane into both aboveground and belowground vegetables, as described in Section 3.1.3.1.6.

4.1.3.2.6 Surface-Water Exposure Point Concentrations

Recreational users who ingest surface water that has migrated from groundwater beneath the site were evaluated. The maximum detected concentration of sulfolane collected during the 2012 field season from adjacent to a frozen surface-water body was assumed to represent groundwater that has migrated offsite to downgradient water bodies. Summary statistics and the surface-water EPC are presented in Table 3-10.

4.1.3.3 Exposure Parameters

Exposure parameter values that were identified for each receptor at the site for the ARCADIS Comparative Scenario are provided in Table 3-12. The exposure parameters were identical to the exposure parameters used in the PPRTV Scenario, and were based primarily on those provided in ADEC (2010a) and USEPA (1989, 1991, 1997a and 2004a) as well as other sources, as noted. These exposure parameters meet or exceed the USEPA (1989) approach for estimating RME, which is the maximum exposure that is reasonably expected to occur in a population. Its intent is to estimate a high end exposure case (i.e., well above the average case) that is still within the range of possible exposures (USEPA 1989). Mathematically, the RME estimate for each exposure pathway combines high end values and assumptions with average values and assumptions. These assumptions tend to maximize estimates of exposure, such as choosing a value near the high end of the concentration or intake range. Therefore, the RME estimates tend to be at the high end of the exposure range, generally greater than the 90th percentile of the population.

4.1.3.4 Assessment of Potential Lead Exposures

The potential hazard associated with lead exposure was evaluated by comparing the predicted blood-lead concentrations to the CDC blood-lead threshold concentration. The threshold lead concentration is 10 µg/dL of whole blood based on potentially adverse neurological effects in children (CDC 2011). A blood-lead concentration of less than 10 µg/dL was deemed acceptable. The USEPA's (2009b) ALM model, which estimates the blood-lead levels of workers and the fetus of a pregnant worker, was used to evaluate the potential onsite exposure to lead in groundwater for the receptors evaluated.

4.2 Toxicity Assessment

The toxicity assessment identified toxicity values that relate exposure (dose) to potential risk or hazard for each COPC. Toxicity values derived from dose-response data were combined with estimates of exposure to characterize potential noncarcinogenic hazard and carcinogenic risk. Toxicity profiles were provided for risk/hazard drivers and sulfolane. Selection of toxicity values followed the hierarchies described below.

4.2.1 Noncarcinogenic Toxicity Values

Chronic and subchronic RfDs were used to evaluate potential adverse effects from ingestion, dermal and inhalation (dust) exposures to noncarcinogenic COPCs. Chronic RfDs, which correspond to 7 or more years of exposure, are specifically developed to be protective of long-term exposures to a constituent with a considerable margin of safety, which usually exceeds 1,000-fold. The USEPA (1989) defines the chronic RfD as "a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime."

As described in detail in Appendix H, ARCADIS scientifically evaluated the existing RfDs and equivalent toxicological reference values for sulfolane and derived chronic and subchronic RfDs per its best professional judgment in accordance with USEPA guidance for evaluation of primary toxicology studies (USEPA 2002d, 2003) and the derivation of RfDs (USEPA 1994, 2002e). Additional context for these decisions is provided in Appendix K. For all other COPCs, the following sources were used to identify chronic toxicological reference values:

- USEPA (2012a) IRIS.
- USEPA PPRTVs, derived by the USEPA's Superfund Health Risk Technical Support Center for the USEPA Superfund program. Current values were obtained directly from the USEPA.
- CalEPA reference exposure levels from the California OEHHA.
- ATSDR MRLs (ATSDR 2012) Chronic MRLs were used to evaluate chronic exposure.
- USEPA (1997b) HEAST.

The USEPA (1989) defines exposures lasting between 2 weeks and 7 years as subchronic exposures. As a result, the short-duration and intermittent nature of construction/trench worker and child and infant exposures require consideration of subchronic toxicity values (subchronic RfDs) to estimate the potential for effects. Subchronic RfDs are developed to be protective of subchronic exposures to constituents with a considerable measure of safety, which usually exceeds 1,000-fold (USEPA 1989). Subchronic RfDs for ingestion (oral) and inhalation (dust and vapor) exposure were identified from the following sources, in the following order of priority, for constituents other than sulfolane:

- USEPA PPRTVs. Current values were obtained directly from the USEPA.
- ATSDR MRLs (ATSDR 2012). Intermediate MRLs were used to evaluate subchronic exposure.
- USEPA (1997b) HEAST.

For the ARCADIS Comparative Scenario, subchronic RfDs, if available, were used to evaluate potential exposures to onsite construction/trench workers and offsite infants given that the period of exposure for these potential receptors is less than 7 years. If subchronic RfDs were unavailable, then only chronic RfDs were used. Despite the 6 year exposure frequency of the child offsite resident, chronic RfDs were used in the ARCADIS Comparative Scenario to evaluate potential exposures to this receptor. Refer to Section 4.5 for a discussion of uncertainties related to the use of chronic values for the child receptor.

Current USEPA guidance recommends calculating a dermal RfD by multiplying the oral RfD by the ABSGI. This recommendation requires one of the following:

- A critical study upon which the toxicity value is based employed an administered dose (e.g., delivery in diet or by gavage) in its design.

- A scientifically defensible database exists that demonstrates that the gastrointestinal absorption of the constituent in question from a medium (e.g., water, feed) similar to the one employed in the critical study is significantly less than 100 percent (e.g., less than 50 percent).

Values for ABSGI were obtained from RAGS (USEPA 2004a). Chronic and subchronic RfDs are presented in Table 3-13.

4.2.2 Carcinogenic Toxicity Values

Oral CSFs and IUR factors were used to evaluate potential carcinogenic effects from ingestion, dermal and inhalation exposures to COPCs. CSFs quantitatively describe the relationship between dose and response. A CSF represents the 95% UCL of the slope of the dose-response curve and is derived using a low-dose extrapolation procedure that assumes linearity at low doses. By applying a CSF to a particular exposure level of a potential carcinogen, the upper bound lifetime probability of an individual developing cancer related to that exposure can be estimated.

CSFs have been developed for the oral and inhalation (dust particulates) exposure routes; IURs have been developed for the inhalation exposure route. CSFs for oral and IURs for inhalation exposures were identified from the following sources, in the following descending order of priority:

- USEPA (2012a) IRIS.
- USEPA PPRTVs. Current values were obtained directly from the USEPA.
- CalEPA (2012) OEHHA Toxicity Criteria Database.
- USEPA (1997b) HEAST.

As is the case for noncarcinogenic toxicity, the USEPA has not developed dermal CSFs for use in risk assessment. Dermal CSFs were calculated in a manner similar to that of noncarcinogenic RfDs for dermal exposure by dividing the oral CSFs by the ABSGI AF (USEPA 2004a). CSFs are presented in Table 3-13.

4.2.3 Sulfolane Toxicity Values

Toxicity values for sulfolane are not presented in IRIS (USEPA 2012a). However, a PPRTV chronic oral RfD of 0.001 mg/kg-day and a PPRTV subchronic oral RfD of 0.01 mg/kg-day have been prepared for sulfolane (USEPA 2012b). The study and approach used to develop the oral RfDs were evaluated to assess potential sulfolane exposures and hazards at the site. In addition, the studies and approaches used by several other regulatory agencies to derive oral RfDs or Public Health Action Levels were evaluated.

Based on a careful and extensive review of this information, ARCADIS derived and documented the ARCADIS oral RfDs of 0.01 mg/kg-day (chronic) and 0.1 mg/kg-day (subchronic).

The ARCADIS evaluation is outlined in Appendix H with complete reference citations. As explained there, the USEPA derived a PPRTV for sulfolane using a no adverse effect level (NOAEL) approach rather than deriving a benchmark dose as has been recommended in USEPA guidance (USEPA 2000a) since 2000 and is favored in the United States for derivation of toxicological reference values for HHRA. The USEPA stated that a benchmark dose could not be derived from the sulfolane data because of a lack of “fit” of the data. The USEPA did not explain why it did not proceed to log transform the data, a step that is appropriately taken per USEPA guidance and practice. When the sulfolane data are log transformed, an excellent “fit” is obtained. Therefore, using benchmark dose modeling in this situation is preferable to using an NOAEL approach, because the model will allow the value to be informed more fully by the data and by the inferences we can reasonably draw from the data. For this and other reasons, ARCADIS disagreed with the science policy decisions made in deriving the sulfolane PPRTVs and derived alternative RfDs

Appendix H also provides the reasons why the Public Health Action Levels derived by ATSDR (2010, 2011) were not meant to be used and should not be used to derive an oral RfD for sulfolane for use in an HHRA.

In addition to evaluating sulfolane’s toxicological profile, ARCADIS has considered the analysis offered by former USEPA official William Farland. Dr. Farland’s credentials and scientific evaluation of sulfolane are contained in Appendix K. Dr. Farland has taken a holistic view of the available information about sulfolane and has assessed its known toxicological profile.

According to Dr. Farland, the sulfolane database has been evolving during the last three decades. Relatively speaking, compared to other industrial chemicals encountered in the environment, the available data and details of their generation are quite robust. A picture emerges of sulfolane as a minimally toxic chemical at low levels in a variety of animal test systems. The effects seen at low doses represent subtle changes that are generally considered to be of unclear toxicological significance and may represent reversible, "adaptive" responses rather than precursors to toxicity. The recent assessments have illustrated the differences in opinion and policy judgments that can arise when subtle effects with questionable toxicological significance identify points of departure for risk assessment purposes. This lack of consensus on which study to use as the "critical study" and the lack of a consistent method of assessment supports the argument that the observations in these studies provide an uncertain basis for health risk assessment and provide "screening-level values."

The assessment activities discussed above have produced a provisional health guidance value (ATSDR) and PPRTVs, including a provisional RfD (USEPA 2012b). It is important to remember that these RfD-equivalent values are not a boundary between safety and risk. A variety of uncertainties are present when extrapolating from such effects in animals to human populations and from partial lifetime studies in animals to longer term potential exposures in humans. Many of these uncertainties are inherent in the policy choices available to risk assessors and are compounded when multiple policy choices are chosen in a given assessment, such as for sulfolane.

The ARCADIS Comparative Scenario risk assessment presents estimated hazards for potential sulfolane exposures using the ARCADIS-derived oral RfDs for sulfolane (Appendices F and G).

4.2.4 Toxicity Equivalence Factors for Polynuclear Aromatic Hydrocarbons

As shown in Tables 3-2a and 3-2b, some carcinogenic PAHs have been identified as COPCs in soil. Following ADEC (2010a) guidance, TEFs were used to assess risks to carcinogenic PAHs, including benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene and indeno(1,2,3-c,d)pyrene). TEFs were applied to EPCs of all carcinogenic PAHs in surface and subsurface soil to equivalent concentrations of benzo(a)pyrene (USEPA 2011c) and total risk was derived for the carcinogenic PAH COPCs. The assessment of potential exposures to other PAHs also included PAHs identified as COPCs in soil based on analytical data collected during the 2011 field season.

4.3 Risk Characterization – ARCADIS Comparative Scenario

This section presents the ARCADIS Comparative Scenario and provides estimated ELCRs and HIs for potentially complete and significant exposure pathways identified in Section 4.1.1.4 for on- or offsite

potential receptors, based on the ARCADIS-derived toxicity criteria for sulfolane and the exposure parameters presented in Table 3-12.

4.3.1 Risk Characterization

The risk characterization integrates results of the data evaluation, exposure assessment and toxicity assessment to evaluate potential risks associated with exposure to site COPCs. The basis for the risk characterization is the quantitative evaluation of potential exposure by potential receptors to COPCs, which consists of estimating carcinogenic risk and noncarcinogenic hazard. This quantitative evaluation of risk and hazard generally provides a health-protective representation of the upper end (potentially highest exposures) for a receptor. The quantitative methods used to calculate noncarcinogenic hazard and carcinogenic risk are presented below. Consistent with USEPA (1989) guidance, the potential for carcinogenic and noncarcinogenic risks were evaluated separately.

4.3.1.1 Carcinogenic Risk

For potential carcinogens, risk was estimated as the incremental probability of an individual developing cancer during a lifetime as a result of RME to a potential carcinogen and was calculated as follows:

$$ELCR = LADDi \times CSFi$$

Where:

ELCR = excess lifetime cancer risk (unitless)

LADDi = lifetime average daily dose for the *i* th constituent (mg/kg BW-day)

CSFi = cancer slope factor for the *i* th constituent $(mg/kg\ BW\text{-}day)^{-1}$.

The CSF converts intake averaged over a lifetime of exposure to the incremental lifetime risk of an individual developing cancer. This linear equation is only valid at low risk levels (i.e., below estimated risks of one in 100) and is an upper-bound estimate based on the 95% UCL of the slope of the dose-response curve. Therefore, the actual risk will be lower than the predicted risk. Potential risk was assumed to be additive, and risks from different possible and probable carcinogens and pathways were summed to evaluate the overall risk. Pathway-specific risks were calculated as the sum of risks from potential carcinogenic COPCs within each exposure pathway, and the total ELCR for each receptor was calculated by summing the risk estimates for the exposure pathways evaluated.

For inhalation of COPCs, the following equation from USEPA (2009a) RAGS Part F was used to assess ELCRs:

$$ELCR = LAEC * IUR$$

Where:

ELCR = excess lifetime cancer risk (unitless)

LAEC = lifetime average exposure concentration ($\mu g/m^3$)

IUR = inhalation unit risk $(\mu g/m^3)^{-1}$

Scientific notation was used to express potential carcinogenic risks. For example, a value of $1x10^{-6}$ is equal to one in 1 million (or 0.000001). The ADEC (2010a) compares individual constituent risk estimates to an acceptable cumulative ELCR of 1×10^{-5} (1 in 100,000. The acceptable cancer risk is the incremental risk attributed to the estimated upper-bound exposure (i.e., RME) to COPCs at the site. This acceptable risk is, by definition, independent of risks associated with non-site-related constituent exposures and other background cancer risks (USEPA 1989). It is standard USEPA and ADEC practice, however, to assess risks and hazards first with background constituents included and then discuss the risks in the absence of the background impacts to inform the decision makers about the risks of site-related constituents.

4.3.1.2 Noncarcinogenic Hazard

The HQ approach was used to characterize the overall potential for noncarcinogenic effects associated with exposure to multiple constituents. This approach assumes that chronic exposures to multiple constituents are additive. For direct-contact and inhalation of particulates exposures, the HQ was calculated as follows:

$$HQ = ADD / RfD$$

Where:

HQ = hazard quotient (unitless)

ADD = average daily dose (mg/kg-day)

RfD = reference dose $(mg/kg\text{-}day)^{-1}$

For inhalation of volatile COPCs, the following equation from USEPA (2009a) RAGS Part F was used to assess noncancer hazards:

$$HQ = AEC / RfC$$

Where:

HQ = hazard quotient (unitless)

AEC = average exposure concentration ($\mu g/cm^3$)

RfC = inhalation reference concentration $(\mu g/cm^3)^{-1}$

The HQ represents the comparison of exposure (dose) over a specified period of time to an RfD for a similar time period. The estimates of exposure (dose) were calculated based on chronic or subchronic exposures. If the HQ exceeds a value of 1, there is a possibility of adverse health effects. The magnitude of the HQ is not a mathematical prediction of the severity or incidence of the effects, but rather indicates that effects may occur. The constituent HQs were summed to calculate an HI for a pathway or site, and the USEPA (1989) recommends that the total HI for the constituents and pathways assessed not exceed a value of 1. An HI of less than 1 indicates that adverse health effects are not likely to occur from exposure to assessed constituents. HQs or HIs of greater than 1 do not indicate that significant risks are present, but rather that additional evaluation may be required to better define the level of risk.

According to the USEPA (1989), noncarcinogenic effects should be evaluated based on target organ(s) or toxicity endpoints. The USEPA believes that the assumption of dose additivity is one of the major limitations of the HI approach because it may overestimate the potential for health effects that most likely will not occur if the COPCs affect different organs or act by different mechanisms of action. The USEPA counters the potential for overestimation by specifying segregation of COPCs by effect and mechanism of action and derivation of separate HIs for each group (USEPA 1989). If the total HI exceeds a value of 1, the specific substances will be evaluated so that only substances that affect similar target organs or exhibit a similar mode of action (i.e., similar effects in the same target organs via the same mechanism) are summed. Quantitative estimates of carcinogenic risk and noncarcinogenic hazard were presented for each receptor.

4.3.1.3 Risk Characterization of Petroleum Hydrocarbon Compounds

In accordance with ADEC (2008b) Cumulative Risk Guidance, individual risks from exposure to GRO, DRO and RRO were calculated using RfDs provided by ADEC (2010a). However, these risk calculations

were not included in cumulative risk estimates. Consistent with ADEC (2008b) Cumulative Risk Guidance, cumulative risks for each receptor were estimated using indicator constituents, as discussed below.

In general, quantitative risk calculated from individual petroleum constituents is considered adequate to account for risk in cumulative risk calculations from petroleum mixtures (ADEC 2008b). The key constituents of petroleum products associated with risk (e.g., PAHs, BTEX, methyl tertiary butyl ether) are included in the quantitative cumulative risk calculations and should adequately describe human health risk from exposure to site media.

4.3.2 Estimated Risks and Hazards for ARCADIS Comparative Scenario

For each total estimated ELCR and HI, the primary exposure pathway and contributing COPC(s) are indicated, as appropriate. This section presents ELCRs and HIs for potential onsite receptors (Section 4.3.2.1) and for potential offsite receptors (Section 4.3.2.2). For each potential receptor, ELCRs and/or HIs are summarized based on possible exposure to maximum and/or 95% UCL-based EPC COPC concentrations. Appendices D and E present complete risk calculations for ELCRs and HIs based on maximum (onsite construction/trench worker and recreational user exposures only) and 95% UCL COPC concentrations, respectively.

Summaries of the cumulative ELCRs and estimated HIs for the receptors evaluated under the ARCADIS Comparative Scenario are presented in the following tables:

- Tables 4-1 and 4-2 present the ELCR and HI summaries for on and offsite receptors using the maximum detected on and offsite values and the 95% UCL on and offsite values, respectively.
- Tables 4-1, 4-3a and 4-4a present ELCR and HI summaries for potential on and offsite receptors based on maximum COPC concentrations for all wells in each EU (including EU-1 because the maximum for all offsite wells is located in this EU).
- Table 4-2 presents ELCR and HI summaries for potential on and offsite receptors at EU-1 based on 95% UCL EPCs.
- Table 4-3a presents ELCR and HI summaries for offsite receptors based on maximum COPC concentrations at EU-2 wells.
- Table 4-4a presents ELCR and HI summaries for offsite receptors based on maximum COPC concentrations at EU-3 wells.

The ARCADIS Comparative scenario risk calculations are presented in Appendix D (maximum concentrations) and Appendix E (95% UCL EPCs).

The total estimated ELCRs presented in Tables 4-1 through 4-4b include arsenic as a soil COPC (arsenic was excluded as a COPC in groundwater). Based on an evaluation of arsenic in soil samples at the site, the presence of arsenic is due to background concentrations. Detected concentrations of arsenic in soil samples collected at the site are evaluated in the 2012 Revised Site Characterization Report (Barr 2012). This evaluation compared site arsenic concentrations to background studies collected in Alaska and evaluated the spatial distribution of arsenic with respect to site operations and other COPCs. The results of the evaluation concluded that the presence of arsenic in soil does not appear to be associated with refinery operations and is likely a result of background concentrations.

4.3.2.1 Estimated Risks and Hazards for Potential Onsite Receptors

Potential onsite receptors evaluated include current and future indoor and outdoor commercial workers, construction/trench workers and adult visitors. The ARCADIS-derived oral RfD was used to evaluate potential sulfolane exposures. The maximum onsite concentration of sulfolane in groundwater detected above the laboratory reporting limit between 2009 and 2011 is 10.4 mg/L. Estimated risks and hazards for the onsite receptors using maximum detected concentrations and 95% UCLs as EPCs are summarized in Table 4-1 and Table 4-2, respectively.

4.3.2.1.1 Onsite Indoor Commercial/Industrial Workers

Table D-25 (Appendix D) presents the estimated ELCRs and HIs for indoor commercial/industrial workers, based on exposures to maximum detected COPC concentrations in groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors (see Table 4-1). The total estimated ELCR is 1×10^{-5} and the total estimated HI is 0.2.

Table E-23 (Appendix E) presents the estimated ELCRs and HIs for indoor commercial/industrial workers, based on exposures to 95% UCLs of detected COPC concentrations in groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors (see Table 4-2). The total estimated ELCR is 1×10^{-6} and the total estimated HI is 0.02.

4.3.2.1.2 Onsite Outdoor Commercial/Industrial Workers

Table D-26 (Appendix D) presents the estimated ELCRs and HIs for outdoor commercial/industrial workers, assuming potential exposure to 95% UCLs of COPC concentrations in surface soil. Table D-26 also shows estimated ELCRs and HIs based on direct-contact exposures, including ingestion of, dermal contact with and inhalation of dust particles from surface soil. The total estimated ELCR is 5×10^{-6} and the total

estimated HI is 0.05 (see Table 4-1). Soil ingestion contributes most to the total estimated ELCR and HIs. Arsenic is the primary risk and hazard driver. Excluding the estimated arsenic ELCR and HI, which are likely due to background, the total estimated ELCR is 2 x 10^{-7} and the total estimated HI is 0.03 (see Table D-26).

4.3.2.1.3 Onsite Construction/Trench Workers

The ARCADIS-derived subchronic oral RfD for sulfolane was used to estimate potential construction/ trench worker hazards in the ARCADIS Comparative Scenario. Table 4-1 and Table D-27a (Appendix D) present the estimated ELCRs and HIs for construction/trench workers based on potential exposures to maximum COPC concentrations in surface and subsurface soil, assuming direct-contact exposures including ingestion, dermal contact and inhalation of dust particles. The total estimated ELCR associated with potential exposure to COPCs in soil is 1 x 10^{-6} and the total estimated HI is 0.3. The soil ingestion pathway contributes most to the total soil-related estimated ELCR and HI. Excluding the estimated arsenic ELCR, which is likely based on background, the total estimated ELCR is 3 x 10^{-7} and the total estimated HI is 0.3.

Table 4-1 and Table D-27b (Appendix D) present ELCRs and HIs based on incidental ingestion of and dermal contact with groundwater in an onsite excavation trench, and inhalation of VOCs within trench air from groundwater based on maximum COPC concentrations in groundwater. The total estimated ELCR is 3 x 10^{-4} and the total estimated HI is 49. Inhalation of VOCs in the trench air is the exposure pathway that contributes most to the cumulative ELCR and HIs. Benzene, naphthalene and ethylbenzene (as estimated in trench air from groundwater) are the primary risk drivers for the total ELCR. Benzene, naphthalene, xylenes and 1,3,5-trimethylbenzene are the risk drivers for the HI.

Table 4-2 and Table E-25a (Appendix E) present the estimated ELCRs and HIs for construction/trench workers based on 95% UCL COPC concentrations and direct-contact exposures including ingestion of, dermal contact with and inhalation of dust particles in surface and subsurface soil. The total soil-related estimated ELCR is 3 x 10^{-7} and the total soil-related estimated HI is 0.06. Soil ingestion contributes most to the total estimated ELCR and HIs. Excluding the estimated arsenic ELCR and HI, which are likely based on background, the total estimated ELCR is 2 x 10^{-8} and the total estimated HI is 0.05.

Table 4-2 and Table E-25b (Appendix E) present ELCRs and HIs based on incidental ingestion of and dermal contact with groundwater in an onsite excavation trench and inhalation of VOCs within trench air from groundwater based on 95% UCL COPC concentrations. The total estimated ELCR is 3 x 10^{-5} and the total estimated HI is 9. Inhalation of VOCs in the trench air contributes most to ELCR and HIs. Benzene is the primary risk driver for ELCRs and benzene and naphthalene are the primary risk drivers for HIs.

4.3.2.1.4 Onsite Adult Visitors

Table 4-1 and Table D-28 (Appendix D) present the estimated ELCRs and HIs for adult visitors based on maximum COPC concentrations in onsite groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors. The total estimated ELCR is 2×10^{-7} and the total estimated HI is 0.002.

Table 4-2 and Table E-26 (Appendix E) present the estimated ELCRs and HIs for adult visitors based on 95% UCL COPC concentrations in onsite groundwater. Inhalation of VOCs in indoor air from groundwater is the primary exposure pathway for these potential receptors. The total estimated ELCR is 1×10^{-8} and the total estimated HI is 0.0002.

4.3.2.2 Estimated Risks and Hazards for Potential Offsite Receptors

In the ARCADIS Comparative Scenario, potential offsite receptors evaluated include current and future residents; adults (chronic exposures), children (chronic exposures) and infants (subchronic exposures); indoor and outdoor commercial workers (chronic exposures); and construction/trench workers (subchronic exposures). The estimated risks and hazards for offsite receptors using maximum detected concentrations and 95% UCLs as EPCs are summarized in Table 4-1 and Table 4-2, respectively.

4.3.2.2.1 Offsite Adult, Child and Infant Residents

Table 4-1 and Tables D-29a and D-30a (Appendix D) present the estimated ELCRs and HIs for offsite adult and child residents, assuming potential exposure to 95% UCL COPC concentrations in ambient air from onsite surface soil (based on 95% UCL concentrations) using the ARCADIS-derived chronic oral RfD for sulfolane. The total estimated ELCRs for adult and child residents are 4×10^{-8} and 9×10^{-9}, respectively, and the total estimated HIs are both 0.001. Excluding arsenic in soil and the estimated arsenic ELCRs and HIs, which is likely due to background, the total estimated ELCRs for adult and child residents are 4×10^{-8} and 8×10^{-9}, respectively, and the total estimated HIs are both 0.0009 (see Table D-5a [Appendix D] for adult resident and Table D-6a for child resident). Table D-31a presents the estimated ELCR and HI for offsite infant residents, assuming potential exposure to 95% UCL COPC concentrations in ambient air from onsite surface soil using the USEPA (2012b) subchronic ARCADIS-derived oral RfD for sulfolane. The total estimated ELCR for infant residents is 1×10^{-9} and the total estimated HI is 0.0007. Excluding the estimated arsenic ELCR and HI, which is likely due to background, the total estimated ELCR for infant residents is 1×10^{-9} and the total estimated HI is 0.0005.

Table 4-1 and Tables D-29b, D-30b and D-31b (Appendix D) show HIs based on ingestion of the maximum detected concentration of sulfolane in groundwater (i.e., tapwater), applied across the entire offsite area (which also includes EU-1 because the maximum value occurs in this EU), for adults (chronic exposures; Table D-29b), children (chronic exposures; Table D-30b) and infants (subchronic exposures; Table D-31b), respectively. Tables D-29c, D-30c and D-31c present the HIs associated with ingestion of homegrown

produce irrigated with sulfolane-impacted groundwater (maximum detected concentration) for adults (chronic exposures; Table D-29c), children (chronic exposures; Table D-30c) and infants (subchronic exposures; Table D-31c), respectively. Tables D-35 and D-36 present the HIs associated with ingestion of surface water (maximum detected concentration) for adults (chronic exposures; Table D-35) and children (chronic exposures; Table D-36).

As shown in Table 4-1 and Tables D-29b, D-30b and D-31b (Appendix D), using the ARCADIS-derived oral RfDs for sulfolane and the maximum concentration detected in offsite groundwater, the total estimated HIs associated with ingestion of groundwater are 1.2 for adult residents (chronic exposure; Table D-29b), 2.8 for child residents (chronic exposure; Table D-30b) and 0.7 for infant residents (subchronic exposure; Table D-31b), respectively, based on ingestion of tapwater. Table 4-1 and Tables D-29c, D-30c and D-31c present the total estimated HIs associated with ingestion of homegrown produce, including an HI of 0.08 for adult residents (chronic exposure; Table D-29c), 0.2 for child residents (chronic exposure; Table D-30c) and 0.03 for infant residents (subchronic exposure; Table D-31c), respectively. These HIs are based on ingestion of homegrown produce using the ARCADIS oral RfDs for sulfolane, along with the maximum detected offsite sulfolane concentration, a BCF of 1.0 and the 95th percentile *per capita* produce ingestion rates. As shown in Table 4-1 and Tables D-35 and D-36 (Appendix D), using the ARCADIS oral RfDs for sulfolane and the maximum concentration EPC, the total estimated HIs associated with ingestion of surface-water are 0.003 for adult residents (chronic exposure; Table D-35) and 0.02 for child residents (chronic exposure; Table D-36). The surface-water HIs for this receptor group are the same for each EU (Table 4-2, Table 4-3a and Table 4-4a).

Table 4-1 presents the cumulative HIs for this receptor group for all exposure pathways combined based on maximum EPCs which are 1.3 for adult residents, 3.1 for child residents (chronic exposure), and 0.7 for infant residents (subchronic exposure). Table 4-2 also presents the cumulative ELCRs for this receptor group for all exposure pathways combined based on maximum EPCs which are 4 x 10^{-8} for adult residents, 9 x 10^{-9} for child residents (chronic exposure), and 1x 10^{-9} for infant residents (subchronic exposure).

Table 4-2 and Tables E-27a, E-28a and E-29a (Appendix E) present the estimated ELCRs and HIs for adults, children (chronic) and infant (subchronic) residents, respectively, based on inhalation of fugitive windborne dust or vapors from onsite COPCs in surface soil, assuming 95% UCL COPC concentrations. As shown in Table E-27a the total estimated ELCR is 4 x 10^{-8} and the total estimated HI is 0.001 for adult residents (chronic expo sure). For a child resident (chronic exposure), the total estimated ELCR is 9 x 10^{-9} and the total estimated HI is 0.001 (Table E-28a). The total estimated ELCR is 1 x 10^{-9} and the total estimated HI is 0.0007 for the infant resident (subchronic exposure; Table E-29a).

Assuming the 95% UCL concentration for sulfolane in EU-1, Table 4-2 and Tables E-27b, E-28b and E-29b in Appendix E) show estimated HIs based on ingestion of 95% UCL sulfolane concentrations in groundwater (i.e., tapwater) at EU-1 by resident receptors. Using the ARCADIS oral RfDs for sulfolane, the estimated HIs

associated with ingestion of water are 0.5 for the adult resident (chronic exposure; Table E-27b), 1.1 for child resident (chronic exposure; Table E-28b) and 0.3 for infant resident (subchronic exposure; Table E-29b). Tables E-27c, E-28c and E-29c present the total estimated HIs associated with consumption of homegrown produce irrigated with water containing sulfolane in EU-1. The HIs are 0.03 for adult residents (chronic exposure), 0.09 for child residents (chronic exposure) and 0.01 for an infant resident (subchronic exposure), using the ARCADIS oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 4-3a and Tables D-37a, D-38b, D-39a, D-37b, D-38a and D-39b (Appendix D) present HIs based on ingestion of the maximum sulfolane concentration in groundwater (i.e., tapwater) within EU-2 for resident receptors. Using the ARCADIS oral RfDs for sulfolane, the total estimated HIs associated with ingesting tapwater containing maximum sulfolane concentrations in EU-2 are 0.4 for an adult resident (chronic exposure; Table D-37a), 0.9 for a child resident (chronic exposure; Table D-38a) and 0.2 for an infant resident (subchronic exposure; Table D-39a). In addition, Table 4-3a presents HIs associated with consumption of homegrown produce irrigated with groundwater containing the maximum sulfolane concentrations at EU-2. The estimated HIs for consumption of homegrown produce irrigated with water from EU-2 are 0.03 for an adult resident (chronic exposure; Table D-37b), 0.08 for a child resident (chronic exposure; Table D-38b) and 0.01 for an infant resident (subchronic exposure; Table D-38b), using the ARCADIS oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 4-3b and Tables E-33a, E-34a and E-35a (Appendix E) present HIs based on ingestion of the 95% UCL sulfolane concentration in groundwater (i.e., tapwater) within EU-2 for resident receptors. Using the ARCADIS oral RfDs for sulfolane, the total estimated HIs associated with ingesting tapwater containing sulfolane in EU-2 are 0.2 for an adult resident (chronic exposure; Table E-33a), 0.4 for a child resident (chronic exposure; Table E-34a) and 0.09 for an infant resident (subchronic exposure; Table E-35a). In addition, Table 4-3b and Tables E-33b, E-34b and E-35b (Appendix E) present HIs associated with consumption of homegrown produce irrigated with sulfolane-impacted groundwater at EU-2. The total estimated HIs for consumption of homegrown produce irrigated with water from EU-2 are 0.01 for an adult resident (chronic exposure; Table E-33b), 0.03 for a child resident (chronic exposure; Table E-34b) and 0.004 for an infant resident (subchronic exposure; Table E-35b) respectively, using the ARCADIS-derived oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 4-4a and Tables D-43a, D-44a and D-45a (Appendix D) show the estimated HIs based on ingestion of the maximum sulfolane concentration in groundwater (i.e., tapwater) within EU-3 by resident receptors. Using the ARCADIS oral RfDs for sulfolane, the estimated HIs associated with ingestion of tapwater are 0.2 for an adult resident (chronic exposure; Table D-43a), 0.5 for a child resident (chronic exposure; Table D-44a) and 0.1 for an infant resident (subchronic exposure; Table D-45a). In addition to a drinking water scenario, Table 4-4a and Tables D-43b, D-44b and D-45b (Appendix D) present the HIs associated with

consumption of homegrown produce irrigated with the maximum detected sulfolane concentration in groundwater in EU-3. The estimated HIs for consumption of homegrown produce are 0.01 for an adult resident (chronic exposure; Table D-43b), 0.04 for a child resident (chronic exposure; Table D-44b) and 0.006 for an infant resident (subchronic exposure; Table D-45b), using the ARCADIS oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

Table 4-4b and Tables E-39a, E-40a and E-41a (Appendix E) show the estimated HIs based on ingestion of the 95% UCL sulfolane concentration in groundwater (i.e., tapwater) within EU-3 by resident receptors. Using the ARCADIS-derived oral RfDs for sulfolane, the estimated HIs associated with ingestion of tapwater are 0.03 for an adult resident (chronic exposure; Table E-39a), 0.07 for a child resident (chronic exposure; Table E-40a) and 0.02 for an infant resident (subchronic exposure; Table E-41a). In addition to a drinking water scenario, Table 4-4b and Tables E-39b, E-40b and E-41b (Appendix E) present the HIs associated with ingestion consumption of homegrown produce irrigated with sulfolane-impacted groundwater in EU-3. The estimated HIs for consumption of homegrown produce are 0.002 for an adult resident (Table E-39b), 0.005 for a child resident (chronic exposure; Table E-40b) and 0.0007 for an infant resident (subchronic exposure; Table E-41b), using the ARCADIS oral RfDs for sulfolane, along with a BCF of 1.0, and the 95th percentile per capita produce ingestion rates.

4.3.2.2.2 Offsite Indoor Commercial Workers

Table 4-1 and Table D-32 (Appendix D) show the HI based on ingestion of groundwater (i.e., tapwater), assuming the maximum offsite sulfolane concentration and the ARCADIS oral RfD for sulfolane. The total estimated HI is 0.9 for offsite indoor commercial/industrial workers (chronic exposure) based solely on ingestion of tapwater containing sulfolane (see Table D-32 [Appendix D]).

Table 4-2 and Table E-30 (Appendix E) show the HI based on ingestion of groundwater (i.e., tapwater), assuming the 95% UCL offsite sulfolane concentration for EU-1 and the ARCADIS oral RfD for sulfolane. The total estimated HI is 0.3 for offsite indoor commercial/industrial workers (chronic exposure) based solely on ingestion of tapwater containing sulfolane (see Table E-30 [Appendix E]).

At EU-2, two sulfolane groundwater EPCs were used to estimate potential hazards associated with ingestion of groundwater by offsite indoor commercial/industrial workers (chronic exposure). Using the maximum detected offsite sulfolane concentration at EU-2, the estimated HI is 0.3 (Table 4-3a). Comparatively, the HI based on the 95% UCL sulfolane concentration at EU-2 is 0.1. Both HIs were derived using the ARCADIS oral RfD for sulfolane (see Table D-40 [Appendix D] for maximum EPC and Table E-36 [Appendix E] for 95%UCL). Similarly, two sulfolane groundwater EPCs were used to estimate potential hazards associated with ingestion by offsite indoor commercial/industrial workers (chronic exposure) at EU-3. Table 4-4a shows the HI based on ingestion of groundwater (i.e., tapwater), assuming the maximum offsite sulfolane concentration at EU-3 and Table 4-4b shows the corresponding HI based the 95% UCL

offsite sulfolane concentration at EU-3. Both HIs were derived using the ARCADIS oral RfD for sulfolane. Using the maximum detected sulfolane concentration at EU-3, the estimated HI is 0.2; the estimated HI is 0.02 for offsite indoor commercial/industrial workers (chronic exposure) based on the 95% UCL groundwater concentration at EU-3 (see Table D-46 [Appendix D] and Table E-42 [Appendix E], respectively).

4.3.2.2.3 Offsite Outdoor Commercial Workers

Table 4-1 presents the estimated ELCRs and HIs for offsite outdoor commercial workers potentially exposed via inhalation of dust particles from onsite surface soil (0 to 2 feet bgs), using 95% UCL COPC concentrations in onsite surface soil. The total estimated ELCR is 2×10^{-8} and the total estimated HI is 0.0006 (see Table D-33a [Appendix D]). Excluding the estimated arsenic concentrations in surface soil and HI, which are likely attributable to background, the total estimated ELCR is 2×10^{-8} and the total estimated HI is 0.0006 (Table D-9a). Table 4-1 also shows the HI for this receptor assuming ingestion of groundwater (i.e., tapwater) and assuming the maximum offsite sulfolane concentration. The estimated HI is 0.9 for offsite outdoor commercial/industrial workers, based on ingestion of tapwater (see Table D-33b [Appendix D]).

Table E-31a [Appendix E] shows ELCRs and HIs based on inhalation of fugitive windborne dust and vapors from onsite COPCs in surface soil, based on 95% UCL COPC concentrations and the ARCADIS oral RfD for sulfolane. It was assumed that the offsite outdoor commercial worker (chronic exposure) is located at the site boundary; therefore, the estimated ELCRs and HIs will over estimate risk for many offsite commercial worker, based on inhalation of dust and vapors from the site. As shown in Table E-31a [Appendix E], the total estimated ELCR is 2×10^{-8} and the total estimated HI is 0.0006, based on inhalation of dust and vapors in ambient air.

Assuming the 95% UCL and ARCADIS oral RfD for sulfolane in EU-1, the total estimated HI is 0.3 for offsite outdoor commercial/industrial workers (chronic exposure), based on ingestion of groundwater (see Table 4-2 and Table E-31 [Appendix E]).

At EU-2, two sulfolane groundwater EPCs were used to estimate potential hazards associated with ingestion of groundwater: the maximum detected concentration of sulfolane and the 95% UCL of the mean sulfolane concentrations. Using the maximum detected concentration in groundwater at EU-2, the estimated HI is 0.3 for offsite outdoor commercial/industrial workers (chronic exposure) based on ingestion of groundwater (see Table 4-3a and Table D-41 [Appendix D]). Using the 95% UCL sulfolane concentration, the total estimated HI is 0.1 for offsite outdoor commercial/industrial workers at EU-2, based on ingestion of tapwater (chronic exposure; see Table 4-3b and Table E-37 [Appendix E]). Both hazard estimates used the ARCADIS oral RfD for sulfolane.

Similarly, at EU-3, the 95% UCL and maximum sulfolane groundwater concentrations were both evaluated as distinct EPCs to estimate potential hazards associated with ingestion of groundwater by offsite commercial/industrial workers. Using the maximum sulfolane concentration at EU-3, the estimated HI is 0.2 (Table 4-4a and Table D-47 [Appendix D]). Using the 95% UCL sulfolane concentration, the estimated HI is 0.02 for offsite outdoor commercial/industrial workers at EU-3 (see Table 4-4b and Table E-43 [Appendix E]). Both hazard estimates are used the ARCADIS oral RfD for sulfolane.

4.3.2.2.4 Offsite Construction/Trench Workers

The estimated HIs for an offsite construction worker who is potentially exposed to maximum sulfolane concentrations by incidental ingestion of sulfolane in offsite groundwater in excavation trenches is 0.00008 (see Table 4-1 and Table D-34 [Appendix D]). This exposure is subchronic and the HI is derived assuming the maximum offsite sulfolane concentration and using the ARCADIS subchronic oral RfD for sulfolane. As discussed in Section 3.1.1.4, sulfolane is not considered to pose adverse health effects due to inhalation and dermal contact exposures. The total estimated HI is 0.00008 for offsite construction workers, based on incidental ingestion of groundwater while working in trenches.

Tables 4-2, 4-3b and 4-4b show the HIs for potential exposures by the construction worker (subchronic exposure) based on 95% UCL sulfolane concentrations for incidental ingestion of sulfolane in offsite groundwater in excavation trenches in EU-1, EU-2 and EU-3, respectively. The estimated HIs for offsite construction workers, which are based on the ARCADIS subchronic oral RfD for potential groundwater ingestion exposures of groundwater while working in trenches, and 95%UCL sulfolane concentrations, are 0.00003, 0.00001 and 0.000002 in EU-1, EU-2 and EU-3, respectively (see Tables E-32, E-38 and E-44 [Appendix E] for the hazard calculations for this receptor in EU-1, EU-2 and EU-3, respectively). Tables 4-3a and 4-4a show the corresponding HIs for this receptor group based on the maximum sulfolane groundwater concentrations at EU-2 and EU-3, respectively. The estimated HIs for offsite construction workers exposed to maximum groundwater concentrations at EU-2 and EU-3 are 0.00003 and 0.00001, respectively (see Tables D-42 and D-48 [Appendix D]).

4.3.2.2.5 Offsite Adult and Child Recreational Users

Table 4-1 and Tables D-35 and D-36 (Appendix D) show the estimated HIs for offsite adult and child (aged 1 to 6 years) recreational users (i.e., swimmer who may be exposed by incidental, ingestion of sulfolane in surface water), assuming the maximum offsite sulfolane concentration in pore water and the ARCADIS chronic oral RfD for sulfolane. The total estimated HIs are 0.003 and 0.02 for offsite adult (chronic exposure) and child recreational users (chronic exposure), respectively.

4.3.3 Conclusions for ARCADIS Comparative Scenario

Table 4-1 presents the estimated ELCRs and HIs using maximum COPC concentrations in onsite subsurface soil, maximum onsite COPC surface soil and groundwater concentrations, maximum offsite groundwater concentrations of sulfolane, and the ARCADIS oral RfDs for sulfolane. The estimated HIs are below the target HI of 1 for the onsite commercial/industrial worker, onsite commercial/industrial outdoor worker, onsite visitor, offsite indoor and outdoor commercial workers, off-site construction/trench workers, and offsite adult and child recreators. The estimated HIs exceed the target HI of 1 for onsite construction/trench workers, and offsite adult and child residents. The HI is equal to 49 for onsite construction workers based on inhalation of volatile COPCs in trench air from groundwater. Benzene, naphthalene, xylenes and 1,3,5-trimethyl benzene are the hazard drivers in the construction worker inhalation scenario. For offsite adult and child resident receptors, the HIs are equal to 1.3 and 3.1, respectively.

As shown in Table 4-2, using the 95% UCL COPC sulfolane concentrations in EU-1, the HIs and ELCRs for offsite construction workers, offsite adult and infant residents (subchronic exposure); and offsite indoor and outdoor commercial workers, and offsite recreators are below the target levels. Assuming the 95% UCL concentration for sulfolane in EU-1, the estimated HIs associated with ingestion of water is 1.1 for a child resident (chronic exposure; Table E-28b).

Table 4-3a presents the estimated ELCRs and HIs using the maximum COPC sulfolane concentrations in EU-2. Under the ARCADIS Comparative Scenario using maximum COPC concentrations in EU-2, the HIs and ELCRs for offsite construction workers, offsite adult, child (chronic exposure) and infant residents (subchronic exposure); and offsite indoor and outdoor commercial workers, and offsite recreators are below the target levels.

As shown in Table 4-3b, using the 95% UCL COPC sulfolane concentrations in EU-2, the HIs and ELCRs for offsite construction workers, offsite adult, child (chronic exposure) and infant residents (subchronic exposure); and offsite indoor and outdoor commercial workers, and offsite recreators are below the target levels.

Table 4-4a presents the estimated ELCRs and HIs using the maximum COPC sulfolane concentrations in EU-2. Under the ARCADIS Comparative Scenario using maximum COPC concentrations in EU-3, the HIs and ELCRs for offsite construction workers, offsite adult, child (chronic exposure) and infant residents (subchronic exposure); and offsite indoor and outdoor commercial workers, and offsite recreators are below the target levels.

As shown in Table 4-4b, using the 95% UCL COPC sulfolane concentrations in EU-3, the HIs and ELCRs for offsite construction workers, offsite adult, child (chronic exposure) and infant residents (subchronic

exposure); and offsite indoor and outdoor commercial workers, and offsite recreators are below the target levels.

4.4 Evaluation of Potential Exposures to Lead in Onsite Groundwater

The USEPA's (2009b) ALM was used to evaluate current and future onsite outdoor commercial/industrial workers and construction/trench workers potentially exposed to lead in onsite groundwater. The maximum concentration of lead detected above the laboratory reporting limit in onsite groundwater is 2.05 µg/L. The USEPA's threshold lead concentration of 10 µg/dL of whole blood is based on potentially adverse neurological effects in children (CDC 2011). The 95th percentile PbB among fetuses of onsite adult workers, assuming potential exposure to the maximum detected concentration in onsite groundwater, was calculated using the ALM (USEPA 2009b). Using the groundwater ingestion rates and exposure frequencies for current and future onsite outdoor commercial/industrial workers and construction/trench workers presented in Table 3-12, the calculated probabilities that fetal PbBs are greater than10 µg/dL are 0.005 and 0.002%, respectively. Thus, potential exposures to lead in groundwater at the site are below the regulatory level of concern and are not expected to pose adverse health effects to current and future onsite outdoor commercial/industrial workers and construction/trench workers. The Calculations of Blood Lead Concentrations spreadsheet is provided in Appendix I.

Based on the results of the ALM (USEPA 2009b), the maximum detected concentration of lead in onsite groundwater is not expected to pose adverse health effects to current and future onsite outdoor commercial/industrial workers or construction/trench workers.

4.5 Uncertainty Assessment – ARCADIS Scenario

Each exposure parameter value and toxicity value incorporated into the HHRA is associated with some degree of uncertainty; these uncertainties may contribute to an overestimation or underestimation of risks at the site (ADEC 2011c). Therefore, key uncertainties associated with each HHRA component (i.e., data evaluation, COPC selection, toxicity assessment, exposure assessment and risk/hazard characterization) were evaluated in the following subsections. In particular, separate analyses were conducted to assess uncertainties related to oral RfDs for sulfolane, BCFs used for plant uptake of sulfolane into homegrown produce, homegrown fruit and vegetable ingestion rates, and exposure assumptions for contact with surface water. To allow a direct comparison illustrating the effect of the toxicity value selection, the ARCADIS Comparative Scenario in Section 4 has been presented with all the exposure parameters requested and approved by ADEC. For further comparison, ARCADIS also has evaluated risk for all receptors based on the ARCADIS-derived toxicity value and the exposure parameters that ARCADIS selected after its literature and data review. These results are presented in Tables4-5 through 4-9 and addressed throughout this Uncertainty Section. Wherever presented, these results are referred to as the "ARCADIS Scenario."

It is ARCADIS' expert scientific opinion that this Scenario is health protective and reflects the use of supportable science policy decisions that are consistent with USEPA guidance and current risk assessment practices.

4.5.1 Data Evaluation

Soil and onsite groundwater samples were analyzed for a large suite of constituents from multiple samples collected throughout the site over time. These samples were analyzed using accepted analytical methodologies. It is unlikely that constituents were overlooked or underestimated by the analytical methods employed. The laboratory data used for soil sulfolane analyses in 2010 and 2011 was not final at the time, but the analytical results have been validated with an approved method.

The release-related constituents detected in soil (e.g., BTEX) were measured in more than 250 soil samples, of which 88 were surface soil samples. The large data set provides high confidence in the 95% UCL on the mean concentrations and in the representativeness of the use of this statistic for EPCs.

A large number of samples of key constituents detected at the site are available for use in the data evaluation. For example, for sulfolane in offsite groundwater, more than 429 samples were grouped by concentration ranges with each range having a high number of samples to represent that zone (i.e., 105 samples in the greater than 100 µg/L EU, 72 samples in the greater than 25 µg/L EU and 252 samples in the EU with detections up to 25 µg/L). The number of samples increases the representativeness of the EPCs based on these groupings of data and it is unlikely that the EPC based on the 95% UCL on the mean concentration underestimates potential exposures to sulfolane given the number of samples. The maximum detected concentration of sulfolane (443 µg/L) is 1.4 times higher than the next highest detection of sulfolane in offsite wells and 3 times greater than the 95% UCL on the mean concentration for the greater than 100 µg/L EU. The ARCADIS Scenario presented in this Uncertainty Section evaluates potential exposures to COPCs in groundwater over each EU using 95% UCL concentrations.

Data for onsite wells with multiple sampling rounds were averaged together and these temporal average well concentrations were grouped to calculate 95% UCL concentrations on the mean. Each temporal average concentration represents multiple sampling events and provides a reliable measure of constituent concentrations in that well. Grouping the data by well to estimate EPCs reduced the number of samples upon which the statistical analysis could be based. Where too few wells were available to reliably estimate 95% UCL values, the highest temporal well average was used to represent the EPC, which is an overestimate of potential exposure.

4.5.2 Constituent of Potential Concern Selection

COPCs were selected from a list of COIs known or suspected to have been used at the site. The approaches used to characterize the site were intended to identify the COPCs in environmental media associated with current and historical site operations. Sampling events were sequentially conducted based on the knowledge obtained from past sampling events. It is likely that these events identified the majority of areas with residual COPCs. While it is possible that some substances may have been omitted, the probability of those substances being important in driving risk is expected to be low. The suite of analyses that was selected represents those constituents that would most likely result from site operations and are therefore the most relevant and appropriate constituents for estimating risks and hazards. Note that analyses of isopropanol and propylene glycol were inadvertently missed during recent groundwater sampling events. Although the potential presence of these constituents is not expected to change the outcome of the risk evaluation, these COPCs will be evaluated once data have been collected.

4.5.3 Toxicity Assessment

Dose-response values are sometimes based on limited toxicological data. For this reason, a margin of safety is built into estimates of both carcinogenic and noncarcinogenic risk, and actual risks are lower than those estimated. The two major areas of uncertainty introduced in the dose-response assessment are: (1) animal to human extrapolation and (2) high to low dose extrapolation. These are discussed below.

Human dose-response values are often extrapolated, or estimated, using the results of animal studies. Extrapolation from animals to humans introduces a great deal of uncertainty in the risk assessment because in most instances, it is not known how differently a human may react to the constituent compared to the animal species used to test the constituent. The procedures used to extrapolate from animals to humans involve conservative assumptions and incorporate several uncertainty factors that overestimate the potential adverse effects associated with a specific dose. As a result, overestimation of the potential for adverse effects to humans is more likely than underestimation.

Predicting potential health effects from exposure to media containing COPCs requires the use of models to extrapolate the observed health effects from the high doses used in laboratory studies to the anticipated human health effects from low doses experienced in the environment. The models contain conservative assumptions to account for the large degree of uncertainty associated with this extrapolation (especially for potential carcinogenic effects) and therefore, tend to be more likely to overestimate than underestimate potential risks.

Oral RfDs for sulfolane have been derived using different approaches and laboratory studies. For this Revised Draft Final HHRA, two potential chronic oral RfDs for sulfolane were used to evaluate hazards:

USEPA (2012b) PPRTV chronic oral RfD of 0.001 mg/kg-day and the ARCADIS-derived chronic oral RfD of 0.01, was derived by ARCADIS. As expected, with a lower sulfolane oral RfD value, the HIs are higher. For example, for the current and future offsite adult resident, based on ingestion of the 95% UCL concentration of sulfolane in groundwater in EU-1, the estimated HIs ranged from 5 using USEPA PPRTV chronic oral RfD of 0.001 mg/kg-day to 0.5 using the ARCADIS-derived chronic oral RfD of 0.01 mg/kg-day that was derived directly from the scientific literature. For the current and future offsite adult resident, based on ingestion of the maximum concentration of sulfolane in groundwater in EU-1, the estimated HI would be 12 using the USEPA PPRTV chronic oral RfD of 0.001 mg/kg-day and 1.2 using the ARCADIS-derived chronic oral RfD of 0.01 mg/kg-day. In addition, two potential subchronic RfDs were used to evaluate hazards associated with subchronic exposures: USEPA (2012b) PPRTV subchronic oral RfD of 0.01 mg/kg-day and the ARCADIS-derived subchronic oral RfD of 0.1 mg/kg-day, which was derived directly from the scientific literature.

For the PPRTV Scenario presented in Section 3, the USEPA PPRTV chronic oral RfD for sulfolane was used to assess potential exposures to children. In the ARCADIS Comparative Scenario presented in Section 4.3, the ARCADIS-derived chronic oral RfD for sulfolane was used to assess potential exposures to children. In the ARCADIS scenario presented in this uncertainty section, two sets of child exposures are presented: one based on the ARCADIS-derived chronic oral RfDs for sulfolane and the other based on the ARCADIS–derived chronic oral RfDs for sulfolane. The subchronic ARCADIS-derived oral RfD for sulfolane was used to assess potential exposures to children (1 to 6 yrs old) in the ARCADIS scenario because chronic RfDs correspond to 7 or more years of exposure and are developed to be protective of long-term exposures to a constituent with a considerable margin of safety, which is typically over 1,000-fold.

As noted in Dr. Farland's toxicological assessment of sulfolane provided in Appendix K, a variety of uncertainties are present when extrapolating from subtle effects in animals to human populations and from partial lifetime studies in animals to longer term potential exposures in humans. Many of these uncertainties are inherent in the policy choices available to risk assessors and are compounded when multiple policy choices are chosen in a given assessment. Risk assessments that evaluate available information and rely on scientific judgment, applied to the chemical constituent and its site-specific exposure characteristics, are typically preferred over risk assessments that make significant use of default positions.

Calculation of a "safe" drinking water level based on the policy choices incorporated for sulfolane would be up to thousands of times below the level where the subtlest potential adverse effects were NOT seen in the animal studies and even many more times below the level where these subtle effects of unknown toxicologic significance were seen. In its recent Health Consultation, the ADHSS (2012) concluded after its own evaluation that "it is unlikely that North Pole residents who drank well water with levels of sulfolane higher than ATSDR's recommended levels would experience health effects resulting from exposure to sulfolane."

4.5.4 Exposure Assessment

According to USEPA (2001) guidance, screening-level estimates of exposure and risk calculations use assumptions that maximize the estimate of risk to ensure that only those constituents that represent a *de minimis* risk are eliminated from further consideration, and those that potentially pose an unacceptable risk will be retained for consideration in subsequent steps of the risk assessment process. As requested by the ADEC, maximum concentrations of COPCs were used as EPCs in the risk calculations for the potential receptors evaluated for the PPRTV Scenario (Section 3) and the ARCADIS Comparative Scenario (Section 4.3). More often, a conservative estimate of average concentrations of constituents is used to represent EPCs (USEPA 1989, 2002c, 2006b, 2007). Potential receptors are more likely to be exposed to a range of these concentrations represented by the average or 95% UCL concentration. As such, the PPRTV Scenario and the ARCADIS Comparative Scenario also present risk results based on the 95% UCL concentrations. Because groundwater data collected from off-site wells indicate that offsite sulfolane concentrations are generally not increasing, the use of the maximum concentration will overestimate the true risk for most, actual receptors.

Concentrations of VOCs in indoor air of current and future onsite commercial/industrial structures were estimated using concentrations of VOCs in groundwater at the site. Due to the uncertainties associated with partitioning from soil to soil gas, ITRC (2007b) does not recommend using soil data as a source of COPCs to evaluate potential vapor intrusion. Thus, use of soil data to evaluate potential soil vapor concerns is inappropriate. USEPA (2002a) and ITRC (2007a) recommendations concluded that there is insufficient scientific support for this procedure. ITRC (2007a) notes “Scientific studies have failed to show good correlation between soil and soil gas sampling and analysis on a consistent basis.” They conclude by recommending that soil data should be used only as a secondary line of evidence and not as a primary line. Overall, the scientific evidence indicates that use of soil data is not a reliable approach for identifying potential vapor intrusion concerns.

Dermal contact with COPCs in groundwater by current and future onsite outdoor commercial/industrial workers was considered an insignificant exposure pathway. Onsite use of groundwater beneath the site is limited to infrequent fire extinguishing. Fires at the site are very rare and the period of exposure would likely be relatively very short. Thus, exclusion of this potential exposure pathway would not significantly impact ELCR and HI estimates for these possible onsite receptors.

For the offsite CSM, it was assumed that groundwater may be connected with surface water, and pore-water data were collected to evaluate potentially complete exposure pathways for surface water. Pore-water piezometer installation methods needed to be revised for two of the three offsite locations because the surface-water body was frozen and true pore-water samples could not be collected. However, the groundwater samples collected were able to be evaluated for human health risk. Because sulfolane degrades more rapidly in the presence of nutrients and oxygen that would be present in the surface water

(ADHSS 2010), and given the limited groundwater- surface water interchange, the results from these samples likely overestimate the concentration of COPCs in surface water. Thus, the data used for the swimming scenario overestimate human health risk.

Ingestion of offsite groundwater by current and future offsite residents was the primary exposure pathway for these potential receptors and resulted in the relatively highest HIs, including for infants (0 to 1 year). The ingestion rate used for this age group slightly exceeded that used for children (0 to 6 years). It was also assumed that infants do not breastfeed and that their formula was made with tapwater instead of pediatrician-recommended distilled water. Thus, it is highly likely that HI estimates for this receptor were overestimated.

Only potential ingestion exposures were quantitatively assessed for sulfolane. This analysis suggests dermal contact and inhalation exposure routes are not significant for sulfolane, which is supported by ATSDR (2010 and 2011) Health Consultations and animal studies (Brown et al. 1966, Andersen et al. 1977). Although these exposure routes were excluded, inclusion of them would likely not contribute significantly to overall hazard estimates. As described in Section 4.1.1.4, dermal contact and inhalation exposure routes are not significant for sulfolane. These assumptions are based on animal studies that have shown that sulfolane is not readily absorbed through human skin because of its low permeability and is not expected to pose a significant risk via an inhalation exposure route due to its low volatility. Ingestion of sulfolane in impacted environmental media is the appropriate exposure route to assess potential hazards to on and offsite receptors. Estimated hazards based on inhalation and dermal exposure routes are insignificant relative to hazards estimated based on the ingestion exposure route.

Both the ingestion rates of homegrown fruit and vegetables and the FI of each for offsite residents are not known. In the PPRTV Scenario and the ARCADIS Comparative Scenario, ingestion of fruit and vegetables by offsite residents was evaluated based on an assumed consumption rate at a level equivalent to 95% of the population (Table 3-12). However, the USEPA (2011a) recommends use of mean homegrown produce ingestion rates because mean values from their surveys are more stable than upper percentile values and because USEPA's RME scenario is defined as a combination of high end and mean exposure assumptions (USEPA 1989, 1991). Accordingly, the ARCADIS Scenario incorporates the use of mean values.

Alternate exposure parameters used in the ARCADIS Scenario are presented on Table 4-5. This third scenario uses produce consumption parameters per USEPA guidance, which translate to adult fruit and vegetable ingestion rates of 63,000 and 175,000 mg/day, respectively; child resident fruit and vegetable ingestion rates of 69,000 and 81,000 mg/day, respectively; and infant resident fruit and vegetable ingestion rates of 41,850 and 33,750 mg/day, respectively, based on mean *per capita* intakes presented in the USEPA (2011a) EFH Table 9-3. These calculations translate into the assumption that adults will consume approximately 2.2 ounces of fruits and 6 ounces of vegetables a day; children will consume approximately 2.5 ounces of fruits and 2.9 ounce of vegetables a day; and infants will consume approximately 1.5 ounces

of fruits and 1.1 ounces of vegetables a day. The risk assessment in the ARCADIS Scenario (Section 4.5.6, below) assumes that during their first year of life, infants will ingest approximately 59 pounds of homegrown fruits and vegetables. For children and adults, the produce consumption rate is assumed to be approximately 123 and 187 pounds per year of homegrown fruits and vegetables, respectively.

HIs would be approximately three times lower for the ingestion of produce exposure pathway when using the mean *per capita* ingestion rates and keeping all other assumptions the same as presented in Table 3-12. However, even using high-end exposure and uptake assumptions for ingestion of homegrown produce, this is an insignificant exposure pathway compared to ingestion of groundwater.

For the PPRTV Scenario and the ARCADIS Comparative Scenario, a groundwater-to-produce BCF value of 1 was assumed. The ARCADIS Scenario (Section 4.5.6, below) uses a lower groundwater-to-produce BCF value based on literature review and derived from data presented in the Final Results of the North Pole Garden Sampling Project (ADEC 2011b). Specifically, plant tissue concentrations were combined with measured groundwater concentrations from the corresponding drinking water wells to derive a BCF for each plant species using the following equation:

BCF = [sulfolane concentration in plant tissue from garden]/
[sulfolane concentration in water used to irrigate the garden]

Average species-specific BCF values ranged from 0.06 to 0.61, with the lower values associated with roots and vegetable fruits (e.g., tomatoes) and the higher values associated with stems and leaves. These values were further evaluated to calculate a 95% UCL value of 0.32. This BCF was used in the ARCADIS Scenario to evaluate offsite resident ingestion of homegrown produce that has been irrigated with groundwater impacted by sulfolane. Using this BCF and other exposure assumptions for the ARCADIS Scenario (Table 4-5), the HIs for the produce exposure pathway are:

- EU-1 (Table 4-7): 0.003 for adult residents (chronic exposure), 0.01 for child residents (chronic exposure) and 0.001 for infant residents (subchronic exposure).
- EU-2 (Table 4-8): 0.001 for adult residents (chronic exposure), 0.003 for child residents (chronic exposure) and 0.0004 for infant residents (subchronic exposure).
- EU-3 (Table 4-9): 0.0002 for adult residents (chronic exposure), 0.0006 for child residents (chronic exposure) and 0.00007 for infant residents (subchronic exposure).

For the ARCADIS Scenario (Section 4.5.6, below), the adult and child recreational user surface-water ingestion rates of 0.021 and 0.049 liter/hour, respectively, were based on USEPA (2011a) recommended mean values for swimmers from the EFH Table 3-5. Adult and child recreational users were assumed to

swim for 30 and 6 years, respectively, for 30 days per year for 0.5 hour per day. ARCADIS chose its exposure parameters to reflect the short time during which surface-water bodies near North Pole, Alaska may be warm enough to promote swimming. As noted in Tables 4-7, 4-8, and 4-9, HIs calculated for the ARCADIS Scenario that uses the assumptions described in this paragraph are approximately ten times lower (factor of 9.7) than the ARCADIS Comparative Scenario.

4.5.5 Risk Characterization

Some HIs exceed the ADEC acceptable target HI equal to 1, particularly those estimated for onsite construction/worker exposures to volatile COPCs in the air of a trench, which have been modeled from groundwater concentrations. For this Revised Draft Final HHRA, endpoint-specific HIs were not calculated and summing all HQs regardless of endpoint is health-protective. The USEPA acknowledges that adding all HQ or HI values may overestimate hazards, because the assumption of additivity is probably appropriate only for those chemicals that exert their toxicity by the same mechanism (USEPA 1989). Application of endpoint-specific HIs is expected to reduce total HI estimates.

As noted above, the child scenario has been assessed using the chronic oral reference dose, which is by definition a daily dose that is protective for sensitive receptors for lifetime exposures. Many USEPA programs such as the drinking water program use adult scenarios to protect both adults and children. For instance, Federal drinking water standards are derived using adult receptors, and USEPA states that such standards are protective for both adults and children. The use of the child exposure levels and body weights coupled with a chronic reference dose in this section provides an additional margin of exposure, but it is uncertain whether it provides additional public health protection. Appendices and H and K provide additional information on sulfolane's toxicological profile which shows that sulfolane presents no special concerns to children and that focusing public health protection efforts on adult receptors using a chronic reference dose adequately protects children.

4.5.6 Estimated Risk and Hazards for Uncertainty Assessment - ARCADIS Scenario

This section presents a detailed summary of ELCRs and HIs for potential offsite receptors (Section 4.3.2.2) under the ARCADIS Scenario. For each potential receptor, ELCRs and/or HIs are summarized based on possible exposure to maximum soil EPC COPC concentrations and/or 95% UCL-based soil and groundwater EPC COPC concentrations. Potential ELCRs and HIs related to offsite surface water exposures are also presented in this section. Appendix G presents complete risk calculations for onsite and offsite receptors based on 95% UCL soil and groundwater COPC concentrations and maximum assumed surface water concentrations.

Summaries of the cumulative ELCRs and estimated HIs for the receptors evaluated under the ARCADIS Scenario are presented in the following tables:

- Table 4-7 presents ELCR and HI summaries for potential offsite receptors at EU-1 based on 95% UCL soil and groundwater EPCs, as well ELCR and HI summaries for potential offsite surface water exposure based on maximum pore water (assumed surface water) EPCs.

- Table 4-8 presents ELCR and HI summaries for potential offsite receptors based on 95% UCL soil EPCs and 95% UCL groundwater EPCs at EU-2 wells. ELCR and HI summaries for potential offsite surface water exposure based on maximum pore water (assumed surface water) EPCs are also presented in Table 4-8.

- Table 4-9 presents ELCR and HI summaries for potential offsite receptors based on 95% UCL soil EPCs and 95% UCL groundwater EPCs at EU-3 wells. ELCR and HI summaries for potential offsite surface water exposure based on maximum pore water (assumed surface water) EPCs are also presented in Table 4-8.

As noted above, tables 4-6 to 4-9 present ELCR and HI summaries for potential offsite receptors based on 95% UCL COPC groundwater concentrations in each of the offsite EUs (95% UCL COPC groundwater concentrations are presented in Tables 4-6 and 4-7 for EU-1, Table 4-8 for EU-2, and Table 4-9 for EU-3). Potential dust exposures from onsite surface soil are based on 95% UCL surface soil (0 to 2 feet bgs) COPC concentrations.

4.5.6.1 Estimated Risks and Hazards for Potential Offsite Resident Receptors

Potential offsite receptors evaluated in the ARCADIS Scenario include current and future residents (adults, children and infants) and off-site recreators. In these ARCADIS scenarios, potential exposures were evaluated using the ARCADIS-derived oral RfDs for sulfolane that were derived from the scientific literature. Specifically, the ARCADIS-derived chronic oral RfD for sulfolane was used to evaluate potential exposures to adult residents and adult recreational users. Both the chronic and subchronic oral RfDs for sulfolane were used to evaluate child residents and child recreational users, and only the subchronic oral RfD for sulfolane was used to evaluate infant residents exposures.

4.5.6.1.1 Offsite Adult, Child and Infant Residents

Use of the maximum detected concentration of sulfolane in groundwater is overly conservative and over estimates HIs for offsite residents (chronic exposure), as is demonstrated by available data. Evaluation of separate EU data and corresponding 95% UCL concentrations sulfolane concentrations is a more appropriate approach for the reasons discussed previously.

Table 4-7 and Tables G-5a, G-6a and G-7a (Appendix G) present the estimated ELCRs and HIs for offsite resident receptors including resident adults (chronic exposure), resident children (chronic and subchronic

exposure) and resident infants (subchronic exposure), respectively, based on inhalation of soil COPCs associated with fugitive windborne dust or vapors from onsite COPCs in surface soil, assuming 95% UCL COPC concentrations. The total estimated ELCR is 4×10^{-8} and the total estimated HI is 0.001 for an adult resident receptor (chronic exposure; Table G-5a). The total estimated ELCR is 9×10^{-9} and the total estimated HI is 0.001 for child resident receptor (chronic exposure; Table G-6a). For the infant resident receptor (subchronic exposure), the total estimated ELCR is 1×10^{-9} and the total estimated HI is 0.0007 (Table G-7a).

For potential exposures to 95% UCL sulfolane concentrations in groundwater at EU-1, the estimated HIs for offsite residents potentially exposed via ingestion of groundwater (i.e., tapwater) from EU-1 are presented in Table 4-7. The total estimated HIs for offsite resident receptors are 0.5 for adult resident (chronic exposure; Table G-5b [Appendix G]), 1 for child resident (chronic exposure; Table G-6b [Appendix G]) and 0.3 for infant resident (subchronic exposure; Table G-7b [Appendix G]). For potential exposure to sulfolane in homegrown produce irrigated with groundwater in EU-1, the estimated HI for an adult resident is 0.003 (chronic exposure; Table G-5b [Appendix G]), the estimated HI for a child resident is 0.01 (chronic exposure; Table G-6c [Appendix G]) and the estimated HI for an infant resident is 0.001 (subchronic exposure; Table G-7c [Appendix G]). Tables G-11 and G-12 present the HIs associated with ingestion of surface water for adults (chronic exposures; Table G-11) and children (chronic exposures; Table G-12a).

Separate hazards were also evaluated for the resident child receptor based on subchronic toxicity values because the ED for this receptor (6 years) meets the definition of subchronic exposure. Table 4-7 and Table G-6d (Appendix G) presents the estimated ELCRs and HIs for offsite child residents in EU-1, assuming potential exposure to 95% UCL COPC concentrations in ambient air from onsite surface soil using subchronic RfDs, including the ARCADIS-derived subchronic oral RfD for sulfolane. The total estimated ELCR is 9×10^{-9} and the total estimated HI is 0.0007. Excluding the estimated arsenic ELCR and HI, which are likely attributable to background, the total estimated ELCR is 8×10^{-9} and the total estimated HI is 0.0005 (see Table G-6d [Appendix G]).

Table 4-7 and tables G-6e and G-6f (Appendix G) present the estimated HIs for a child resident in EU-1 based on ingestion of the 95% UCL detected concentration of sulfolane in groundwater (i.e., tapwater) and ingestion of homegrown produce, respectively. These scenarios were evaluated using the ARCADIS-derived subchronic oral RfD for sulfolane. The estimated HIs for a child resident assuming subchronic exposures at EU-1 are 0.1 and 0.001 based on ingestion of tapwater and ingestion of homegrown produce, respectively (see Tables G-6e and G-6f [Appendix G]).

Table 4-8 presents the estimated HIs associated with offsite resident receptors potentially exposed to groundwater at EU-2. Assuming the 95% UCL of sulfolane in groundwater at EU-2 and using the alternative oral RfDs for sulfolane derived directly from the scientific literature by ARCADIS, the estimated HI for an adult resident is 0.2 (chronic exposure; Table G-13a [Appendix G]), the estimated HI for a child resident is

0.4 (chronic exposure; Table G-14a [Appendix G]) and the estimated HI for an infant resident is 0.09 (subchronic exposure; Table G-15a [Appendix G]), based on ingestion of tap water. For consumption of homegrown produce irrigated with groundwater from EU-2 (95% UCL), the estimated HIs for offsite resident receptors are 0.001 for adult residents (chronic exposure; Table G-13b [Appendix G]), 0.003 for child residents (chronic exposure; Table G-14b [Appendix G]) and 0.0004 for infant residents (subchronic exposure; Table G-15b [Appendix G]).

Assuming subchronic exposures by a resident child, Table 4-8 includes the estimated HIs using the ARACADIS-derived subchronic oral RfD for sulfolane. The estimated HI is 0.04 for the offsite child resident receptor ingesting groundwater (i.e., tapwater) from ingestion of EU-2 (95% UCL concentration of sulfolane in groundwater (i.e., tapwater) (see Table G-14c [Appendix G]). The estimated HI for this receptor based on subchronic exposure and ingestion of homegrown produce irrigated with groundwater from EU-2 (95% UCL sulfolane concentration) is 0.0003 (see Table G-14d [Appendix G]).

Table 4-9 presents the hazard estimates for potential exposures by offsite resident receptors at EU-3, based on ingestion of tapwater and ingestion of homegrown produce, respectively, assuming the 95% UCL for sulfolane in groundwater and ARCADIS-derived oral RfD for sulfolane. For offsite resident receptors ingesting groundwater (i.e., tapwater), the estimated HIs are 0.03 for the adult resident (chronic exposure; Table G-19a [Appendix G]), 0.07 for the child resident (chronic exposures; Table G-20a [Appendix G]) and 0.02 for the infant resident (subchronic exposures; Table G-21a [Appendix G]). For potential exposures from consumption of homegrown produce in EU-3, the estimated HIs are 0.0002 for the adult resident (chronic exposure; Table G-19b [Appendix G]), 0.0006 for the child resident (chronic exposures; see Table G-20b [Appendix G]) and 0.00007 for the infant resident (subchronic exposures; Table G-21b [Appendix G]).

Assuming subchronic exposures by a resident child, Table 4-9 includes the estimated HIs using the alternative subchronic oral RfD for sulfolane. The estimated HI is 0.007 for the offsite child resident receptor ingesting groundwater (i.e., tapwater) from EU-3 (95% UCL concentration of sulfolane) (Table G-20c [Appendix G]). The estimated HI is 0.00006 for this receptor based on subchronic ingestion of homegrown produce irrigated with groundwater from EU-3 (95% UCL sulfolane concentration) (see Table G-20d [Appendix G]).

4.5.6.1.2 Offsite Adult and Child Recreational Users

The estimated HIs for an offsite adult recreational user (i.e., swimmer) who may incidentally ingest sulfolane in surface water are presented in Table 4-7, 4-8, and 4-9. The estimated HIs are based on the maximum offsite sulfolane concentration in pore water and the ARCADIS-derived chronic oral RfDs for sulfolane. For offsite adult recreational users, the estimated HI is 0.0002 (chronic exposure; Table G-11 [Appendix G]). Tables 4-7, 4-8, and 4-9 also show the estimated HIs for the offsite child (aged 1 to 6 years) recreational user (i.e., swimmer) who may incidentally ingest sulfolane in surface water, assuming the maximum offsite

sulfolane concentration in pore water and using both the ARCADIS-derived chronic and subchronic oral RfDs for sulfolane, respectively. For offsite child recreational users, the HI is 0.002 assuming chronic exposure (Table G-12a [Appendix G]) and 0.0002 assuming subchronic exposures (Table G-12b [Appendix G]).

4.5.7 Conclusions for ARCADIS Scenario

Table 4-7 presents the estimated ELCRs and HIs using 95% UCL COPC concentrations in EU-1. Using the 95% UCL onsite COPC soil concentrations, the 95% UCL onsite and EU-1 offsite sulfolane groundwater concentrations, the ARCADIS-derived oral RfDs for sulfolane, and the alternate ARCADIS exposure assumptions (Table 4-5), the estimated HIs for all receptors evaluated in the ARCADIS Scenario are equal to or below the target HI of 1.

The estimated total ELCRs for the potential receptors evaluated in the ARCADIS Scenario are equal to or below the ADEC acceptable ELCR of 1×10^{-5}.

As shown in Table 4-8, using the 95% UCL COPC concentrations in onsite surface soil and 95% UCL sulfolane concentration in groundwater in EU-2, the estimated HIs are below the target HI of 1 for the potential receptors evaluated. The estimated total ELCRs for the receptors evaluated are below the ADEC acceptable ELCR of 1×10^{-5}.

As shown in Table 4-9, using the 95% UCL COPC concentrations in onsite surface soil and 95% UCL sulfolane concentration in groundwater in EU-3, the estimated HIs are below the target HI of 1 for the potential receptors evaluated. The estimated total ELCRs for the receptors evaluated are below the ADEC acceptable ELCR of 1×10^{-5}.

As demonstrated in this section and in Tables 4-6 through 4-9, there are no offsite potential receptors that exceed the target HI of 1 and no offsite EUs that exceed the acceptable ELCR when the ARCADIS-derived toxicity value is used in combination with the ARCADIS exposure parameters.

5. Site-Specific Alternative Cleanup Levels

The Draft Risk Assessment Procedures Manual (ADEC 2010a, 2011d) provides for ACLs to be calculated for receptors who exceed a target risk level, by setting the total carcinogenic risk to 1 x 10^{-5} or the HI to 1 and solving for the concentration term for each COPC in each medium that contributes significantly to total potential risk ("risk drivers"). Under this method, using the exposure parameters set forth in the PPRTV and ARCADIS Comparative Scenarios, and individual COPC ELCR target risk of 1 x 10^{-5} and HI of 1, ACLs of 0.6, 0.03, 3.5 and 0.09 mg/L were calculated for benzene, naphthalene, xylenes and 1,3,5-trimethylbenzene, respectively, based on incidental ingestion of groundwater in a trench, dermal contact with groundwater and inhalation of trench air by onsite construction workers. Table 5-1 presents the ACLs for the PPRTV, ARCADIS Comparative, and ARCADIS Scenarios, Appendix J provides the calculations.

The ADEC and FHRA continue to discuss and evaluate an appropriate ACL for sulfolane; therefore, no ACL is proposed for sulfolane at this time. Using the various exposure scenarios, toxicological reference values and exposure assumptions presented in this Revised Draft Final HHRA, the range of potential ACLs includes:

- 14 µg/L, derived from the PPRTV RfD and ADEC-approved exposure assumptions (PPRTV Scenario), for a child with chronic exposure
- 145 µg/L, derived from the ARCADIS RfD and ADEC-approved exposure assumptions (ARCADIS Comparative Scenario), for a child with chronic exposure
- 362 µg/L, derived from the ARCADIS RfD and the alternate exposure assumptions (ARCADIS Scenario), for an adult with chronic exposure.

Based on the Margin of Exposure evaluation presented in Appendix K, ARCADIS and Dr. Farland conclude that an ACL within this range would be protective of human health. Table 5-2 provides the ACLs that correspond to the PPRTV, ARCADIS Comparative, and ARCADIS Scenarios for infant (subchronic), child (subchronic and chronic) and adult (chronic) exposures.

In the meantime, as potential sulfolane ACLs are considered, offsite residents and commercial workers located immediately north of the site obtain drinking water from the city's new water supply wells. Individuals located outside the city water service area but within or near the dissolved sulfolane plume have been provided with alternative water supplies by FHRA (including treatment systems, bulk water tanks or continued supplies of bottled water) to eliminate potential ingestion of groundwater impacted with sulfolane.

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Tables

Table 3-1
Constituents of Interest in Soil and Groundwater

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

	Constituent Included in Analyte List					Toxicity Values Available from USEPA			
Constituent of Interest	2000 Characterization Study-Soil [a]	2001 Characterization Study-Soil [b]	2009-2010 Characterization Study-Soil [c]	Historical Groundwater [d]	Included on Refinery Laboratory Spilled Material "Ingredient" List	Oral CSF	IUR	Oral RfD	Inhalation RfC
VOCs									
1,1-Dichloroethene		X	X	X				X	X
1,2,4-Trimethylbenzene		X	X	X	X				X
1,3,5-Trimethylbenzene		X	X	X				X	
1-Chloronaphthalene				X				X	
4-Isopropyltoluene(p-cymene)		X	X	X					
Benzene	X	X	X	X	X	X	X	X	X
Chlorobenzene			X	X				X	X
cis-1,2-Dichloroethene		X		X				X	
Cyclohexane					X				X
Ethylbenzene	X	X	X	X	X	X	X	X	X
Isopropylbenzene (cumene)		X	X	X	X			X	X
Methyl tert-butyl ether (MTBE)				X		X	X		X
Methylene chloride	X			X		X	X	X	X
n-Butylbenzene			X	X				X	
n-Hexane					X			X	X
N-Propylbenzene		X	X	X				X	X
Propylene gylcol (1,2,-Propanediol)					X			X	
Pyridine		X		X				X	
sec-Butylbenzene		X	X	X					
tert-Butylbenzene		X	X	X					
Toluene	X	X	X	X	X			X	X
Trichlorofluoromethane (Freon 11)		X		X				X	X
Xylenes	X	X	X	X	X			X	X
SVOCs									
1,2-Dichlorobenzene		X	X	X				X	X
1,2-Diphenylhydrazine (as Azobenzene)		X		X		X	X		
1,3-Dichlorobenzene		X	X	X					
1-Methylnaphthalene				X		X		X	
2,4,5-Trichlorophenol		X	X	X				X	
2,4,6-Trichlorophenol		X	X	X		X	X	X	
2,4-Dichlorophenol		X	X	X				X	
2,4-Dimethylphenol		X		X				X	
2,4-Dinitrophenol		X	X	X				X	
2,4-Dinitrotoluene		X	X	X		X	X	X	
2,6-Dinitrotoluene		X	X	X				X	
2-Chloronaphthalene		X	X	X				X	
2-Chlorophenol		X	X	X				X	
2-Methylnaphthalene		X	X	X				X	
2-Methylphenol (o-Cresol)		X	X	X				X	X
2-Nitroaniline		X	X	X				X	X
2-Nitrophenol		X	X	X					
3 & 4-Methylphenol (m,p-Cresol)		X	X	X				X	X
3,3-Dichlorobenzidine		X	X	X		X	X		
3-Nitroaniline		X	X	X					
4,6-Dinitro-2-methylphenol		X	X	X					
4-Bromophenyl phenyl ether		X	X	X					
4-Chloro-3-methylphenol		X	X	X					
4-Chloroaniline		X	X	X		X		X	
4-Chlorophenyl phenyl ether		X	X	X					
4-Nitroaniline		X	X	X				X	X
4-Nitrophenol		X	X	X					
Acenaphthene		X	X	X				X	
Acenaphthylene		X	X	X					
Anthracene		X	X	X				X	
Benzo (a) anthracene		X	X	X		X	X		
Benzo (a) pyrene		X	X	X		X	X		
Benzo (b) fluoranthene		X	X	X		X	X		
Benzo (g,h,i) perylene		X	X	X					
Benzo (k) fluoranthene		X	X	X		X	X		
Benzidine				X		X	X	X	
Benzoic Acid		X	X	X				X	
Benzyl alcohol		X	X	X				X	
Bis(2-chloroethoxy)methane		X	X	X				X	
Bis(2-chloroethyl)ether		X	X	X		X	X		
Bis(2-chloroisopropyl)ether		X	X	X		X	X	X	
Bis(2-ethylhexyl)phthalate		X	X	X		X	X	X	
Butyl benzyl phthalate		X	X	X		X		X	
Carbazole				X					
Chrysene		X	X	X		X	X		
Dibenzo (a,h) anthracene		X	X	X		X	X		
Dibenzofuran		X	X	X					
Diethyl phthalate		X	X	X				X	
Dimethyl phthalate		X	X	X					
Di-n-butyl phthalate		X	X	X				X	
Di-n-Octylphthalate			X	X					
Fluoranthene		X	X	X				X	
Fluorene		X	X	X				X	
Hexachlorobenzene		X	X	X		X	X	X	
Hexachlorobutadiene		X	X	X		X	X	X	
Hexachlorocyclopentadiene		X	X	X				X	X
Hexachloroethane		X	X	X		X	X	X	
Indeno (1,2,3-cd) pyrene		X	X	X		X	X		
Isophorone		X	X	X		X		X	X
Isopropanol (propanol)					X				X
Naphthalene		X	X	X	X		X	X	X
Nitrobenzene		X	X	X			X	X	X
N-Nitrosodimethylamine		X	X	X		X	X	X	X
N-Nitrosodi-n-propylamine		X	X	X		X	X		
N-Nitrosodiphenylamine		X	X	X		X	X		
Pentachlorophenol		X	X	X		X	X	X	
Phenanthrene		X	X	X					
Phenol		X	X	X				X	X
Pyrene		X	X	X				X	

Table 3-1
Constituents of Interest in Soil and Groundwater

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent of Interest	Constituent Included in Analyte List				Included on Refinery Laboratory Spilled Material "Ingredient" List	Toxicity Values Available from USEPA			
	2000 Characterization Study-Soil [a]	2001 Characterization Study-Soil [b]	2009-2010 Characterization Study-Soil [c]	Historical Groundwater [d]		Oral CSF	IUR	Oral RfD	Inhalation RfC
Metals									
Antimony	X	X		X				X	
Arsenic	X	X		X	X	X	X	X	X
Barium		X		X	X			X	X
Cadmium		X		X	X		X	X	X
Chromium Total	X	X		X	X	X	X	X	X
Copper				X	X			X	
Iron				X	X			X	
Lead		X		X	X				
Mercury		X		X	X			X	X
Nickel				X	X		X	X	X
Selenium	X			X	X			X	X
Silver		X		X				X	
Zinc				X	X			X	
Other									
Alkanol amines					X				
Alkylamines					X				
Alkylene amines					X				
Calcium					X				
Chloride					X				
Cyanide					X			X	
Di-n-Octylphthalate				X					
Dinonylnaphthylsulfonic acid					X				
Fluoroalkyl Surfactant					X				
Iron Oxides					X				
Isopropanol (propanol)					X				X
2-Methoxymethylethoxy propanol					X				
Monoethanolamine					X				
Montmorillonite, calcined					X				
Phenol					X			X	X
Propylene glycol (1,2-Propanediol)					X			X	
Silica					X				X
Sulfate				X					
Sulfolane			X	X	X			X	
GRO		X	X	X					
DRO		X	X	X					
RRO		X	X	X					
Heavy aromatic naptha (Naphtha, High Flash Aromatic [HFAN])					X				
Heavy paraffinic distillate (mixture)					X				

Notes:
a - Shannon and Wilson, Inc. 2000. Draft Site Characterization and Corrective Action Plan, Williams Alaska Petroleum, Inc., North Pole Refinery. December 2000.
b - Shannon and Wilson, Inc. 2001. Contaminant Characterization Study, Williams Alaska Petroleum, Inc., North Pole Refinery, North Pole, Alaska. October 2001.
c - Barr Engineering Company. 2011. Site Characterization and First Quarter 2011 Groundwater Monitoring Report. May 2011.
d - Included in SWI groundwater database, dated June 2011
USEPA = United States Environmental Protection Agency Integrated Risk Information System (2011)
CSF = Cancer Slope Factor
IUR= Inhalation Unit Risk
RfD = Reference Dose
RfC = Reference Concentration
VOCs - volatile organic compounds
SVOCs - semi-volatile organic compounds
Note, lead is evaluated based on blood lead level.

Table 3-2a
Constituents of Potential Concern in Soil and Groundwater

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Constituents of Interest	Maximum Soil Concentration (mg/kg) [a]	Maximum Observation or MRL Location	ADEC Soil Cleanup Level Based on Migration to Groundwater (mg/kg)	ADEC Soil Cleanup Level Based on Direct Contact (mg/kg)	ADEC Soil Cleanup Level Based on Outdoor Inhalation (mg/kg)	Selected Soil Screening Level [h] (mg/kg)	Soil COPC Selected in the RAWP [b]	Soil COPC in the 2012 HHRA [c]
VOCs								
1,1-Dichloroethene	<1.36	SB-151 (6.7 - 8.4)	0.03	14	0.85	0.03	Yes	Yes
1,2,4-Trimethylbenzene	205	O-2	23	5,100	49	4.9	Yes	Yes
1,3,5-Trimethylbenzene	81.1	10/20/2010 at O-2	23	5,100	42	4.2	Yes	Yes
1-Chloronaphthalene	--		na	na	na	na	No [i]	No [i]
4-Isopropyltoluene (p-cymene)	20.2	10/20/2010 at O-2	na	na	na	na	Yes	Yes
Benzene	82	MW-135	0.025	150	11	0.025	Yes	Yes
Chlorobenzene	<1.36	SB-151 (6.7 - 8.4)	0.63	2,000	200	0.63	Yes	Yes
cis-1,2-Dichloroethene	<1.36	SB-151 (6.7 - 8.4)	0.24	1,000	130	0.24	Yes	Yes
Cyclohexane	44.9	SB-160 (6.4 - 8.4)	13	7,000	na	13	Yes	Yes
Ethylbenzene	111	O-2	6.9	10,100	110	6.9	Yes	Yes
Isopropylbenzene (cumene)	41.6	O-2	51	10,100	62	6.2	Yes	Yes
Methyl tert-butyl ether	<5.4	SB-151 (6.7 - 8.4)	1.3	4,600	290	1.3	Yes	Yes
Methylene chloride	0.188	SB-123 (3.5 - 5.2) & Dup	0.016	1,100	160	0.016	Yes	Yes
n-Butylbenzene	107	O-2	15	1,000	42	4.2	Yes	Yes
n-Hexane	13	SB-123 (6.0 - 8.0)	6.2	570	na	6.2	Yes	Yes
n-Propylbenzene	72.7	O-2	15	1,000	42	4.2	Yes	Yes
Propylene gylcol (1,2,-Propanediol)	--		150	1,200,000	na	150	Yes	No [i]
Pyridine	<35.9	5/30/2001 at B1-4	na	na	na	na	No [i]	No [i]
sec-Butylbenzene	25.3	O-2	12	1,000	41	4.1	No	Yes
tert-Butylbenzene	2.56	MW-176C	12	1,000	70	7	Yes	No
Toluene	392	MW-135	6.5	8,100	220	6.5	Yes	Yes
Trichlorofluoromethane (Freon 11)	22.7	3/8/2001 at MW135	86	30,400	990	86	No	No
Xylenes	706	SB-180 (5.5 - 7.2)	63	20,300	63	6.3	Yes	Yes
SVOCs								
1,2-Dichlorobenzene	<35.9	5/30/2001 at B1-4	5.1	9,100	45	4.5	Yes	Yes
1,2-Diphenylhydrazine (as Azobenzene)	<35.9	5/30/2001 at B1-4	na	na	na	na	No [i]	No [i]
1,3-Dichlorobenzene	<35.9	5/30/2001 at B1-4	28	9,100	69	6.9	Yes	Yes
1-Methylnaphthalene	88.5	O-21 (4.0-6.0)	6.2	280	760	6.2	Yes	Yes
2,4,5-Trichlorophenol	<35.9	5/30/2001 at B1-4	67	6,500	na	67	No	No
2,4,6-Trichlorophenol	<35.9	5/30/2001 at B1-4	1.4	460	4,100	1.4	Yes	Yes
2,4-Dichlorophenol	<35.9	5/30/2001 at B1-4	1.3	230	na	1.3	Yes	Yes
2,4-Dimethylphenol	<35.9	5/30/2001 at B1-4	8.8	1,300	na	8.8	Yes	Yes
2,4-Dinitrophenol	<182	5/30/2001 at B1-4	0.54	160	na	0.54	Yes	Yes
2,4-Dinitrotoluene	<35.9	5/30/2001 at B1-4	0.0093	8.8	na	0.0093	Yes	Yes
2,6-Dinitrotoluene	<35.9	5/30/2001 at B1-4	0.0094	8.9	na	0.0094	Yes	Yes
2-Chloronaphthalene	<35.9	5/30/2001 at B1-4	120	4,700	na	120	No	No
2-Chlorophenol	<35.9	5/30/2001 at B1-4	1.5	510	2,300	1.5	Yes	Yes
2-Methylnaphthalene	240	O-2	6.1	280	750	6.1	Yes	Yes
2-Methylphenol (o-Cresol)	<35.9	5/30/2001 at B1-4	15	3,200	na	15	Yes	Yes
2-Nitroaniline	<182	5/30/2001 at B1-4	na	na	na	na	No [i]	No [i]
2-Nitrophenol	<35.9	5/30/2001 at B1-4	na	na	na	na	No [i]	No [i]
3 & 4-Methylphenol (m,p-Cresol)	<35.9	5/30/2001 at B1-4	1.5	350	na	1.5	Yes	Yes
3,3-Dichlorobenzidine	<73	5/30/2001 at B1-4	0.19	11	na	0.19	Yes	Yes
3-Nitroaniline	<182	5/30/2001 at B1-4	na	na	na	na	No [i]	No [i]
4,6-Dinitro-2-methylphenol	<182	5/30/2001 at B1-4	na	na	na	na	No [i]	No [i]
4-Bromophenyl phenyl ether	<35.9	5/30/2001 at B1-4	na	na	na	na	No [i]	No [i]
4-Chloro-3-methylphenol	<73	5/30/2001 at B1-4	na	na	na	na	No [i]	No [i]
4-Chloroaniline	<73	5/30/2001 at B1-4	0.057	90	na	0.057	Yes	Yes
4-Chlorophenyl phenyl ether	<35.9	5/30/2001 at B1-4	na	na	na	na	No [i]	No [i]
4-Nitroaniline	<35.9	5/30/2001 at B1-4	na	na	na	na	No [i]	No [i]
4-Nitrophenol	<182	5/30/2001 at B1-4	na	na	na	na	No [i]	No [i]
Acenaphthene	<35.9	5/30/2001 at B1-4	180	2,800	na	180	No	No
Acenaphthylene	0.0102	SB-168 (0.0 - 2.0)	180	2,800	na	180	No	No
Anthracene	0.431	SB-134 (5.0 - 6.8)	2,000	20,600	na	2,000	No	No
Benzidine	--		na	na	na	na	No [i]	No [i]
Benzo (a) anthracene	0.0988	DO-21 (6.0-8.0)	3.6	4.9	na	0.49	Yes	Yes [k]
Benzo (a) pyrene	0.0952	DO-21 (6.0-8.0)	2.1	0.49	na	0.049	Yes	Yes [k]
Benzo (b) fluoranthene	0.108	SB-168 (0.0 - 2.0)	12	5	na	0.49	Yes	Yes [k]
Benzo (g,h,i) perylene	0.186	O-12 (0.0 - 2.0)	38,700	1,400	na	140	No	No
Benzo (k) fluoranthene	0.0404	SB-168 (0.0 - 2.0)	120	49	na	4.9	Yes	Yes [k]
Benzoic Acid	<182	5/30/2001 at B1-4	410	317,000	na	410	No	No
Benzyl alcohol	<35.9	5/30/2001 at B1-4	na	na	na	na	No [i]	No [i]
Bis(2-chloroethoxy)methane	<35.9	5/30/2001 at B1-4	na	na	na	na	No [i]	No [i]
Bis(2-chloroethyl)ether	<35.9	5/30/2001 at B1-4	0.0022	7.5	3.3	0.0022	Yes	Yes
Bis(2-chloroisopropyl)ether	<35.9	5/30/2001 at B1-4	na	na	na	na	No [j]	No [j]
Bis(2-ethylhexyl)phthalate	0.0958	SB-105 (5.0 - 6.2)	13	220	na	13	Yes	No
Butyl benzyl phthalate	<35.9	5/30/2001 at B1-4	920	2,900	na	290	No	No
Carbazole	--		6.5	290	na	6.5	No	No
Chrysene	0.783	SB-108 (0.0 - 2.0)	360	490	na	49	No	Yes [k]
Dibenzo (a,h) anthracene	0.018	DO-21 (6.0-8.0)	4	0.49	na	0.049	Yes	Yes [k]

Table 3-2a
Constituents of Potential Concern in Soil and Groundwater

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Constituents of Interest	Maximum Soil Concentration (mg/kg) [a]	Maximum Observation or MRL Location	ADEC Soil Cleanup Level Based on Migration to Groundwater (mg/kg)	ADEC Soil Cleanup Level Based on Direct Contact (mg/kg)	ADEC Soil Cleanup Level Based on Outdoor Inhalation (mg/kg)	Selected Soil Screening Level [h] (mg/kg)	Soil COPC Selected in the RAWP [b]	Soil COPC in the 2012 HHRA [c]
Dibenzofuran	1.31	O-2	11	200	na	11	Yes	No
Diethyl phthalate	<35.9	5/30/2001 at B1-4	130	61,900	na	130	No	No
Dimethyl phthalate	<35.9	5/30/2001 at B1-4	1,100	773,000	na	1,100	No	No
Di-n-butyl phthalate	<35.9	5/30/2001 at B1-4	80	7,900	na	80	No	No
Di-n-Octylphthalate	<35.9	5/30/2001 at B1-4	3,800	3,100	na	310	No	No
Fluoranthene	0.258	DO-21 (6.0-8.0)	1,400	1,900	na	190	No	No
Fluorene	2.56	MW-176C	220	2,300	na	220	No	No
Hexachlorobenzene	<35.9	5/30/2001 at B1-4	0.047	3.2	1.5	0.047	Yes	Yes
Hexachlorobutadiene	<35.9	5/30/2001 at B1-4	0.12	13	3.8	0.12	Yes	Yes
Hexachlorocyclopentadiene	<35.9	5/30/2001 at B1-4	1.3	390	2	0.2	Yes	Yes
Hexachloroethane	<35.9	5/30/2001 at B1-4	0.21	63	170	0.21	Yes	Yes
Indeno (1,2,3-cd) pyrene	0.0688	SB-168 (0.0 - 2.0)	41	5	na	0.49	Yes	Yes [k]
Isophorone	<35.9	5/30/2001 at B1-4	3.1	5,300	na	3.1	Yes	Yes
Isopropanol (propanol)	--		na	na	na	na	Yes	Yes
Naphthalene	125	O-2	20	1,400	28	2.8	Yes	Yes
Nitrobenzene	<35.9	5/30/2001 at B1-4	0.094	51	120	0.094	Yes	Yes
N-Nitrosodimethylamine	<35.9	5/30/2001 at B1-4	0.000053	0.16	0.19	0.000053	Yes	Yes
N-Nitrosodi-n-propylamine	<35.9	5/30/2001 at B1-4	0.0011	0.52	na	0.0011	Yes	Yes
N-Nitrosodiphenylamine	<35.9	5/30/2001 at B1-4	15	750	na	15	Yes	Yes
Pentachlorophenol	<182	5/30/2001 at B1-4	0.0047	39	na	0.0047	Yes	Yes
Phenanthrene	5.6	MW-176C	3,000	20,600	na	2,060	No	No
Phenol	<35.9	5/30/2001 at B1-4	68	23,200	na	68	No	No
Pyrene	0.278	DO-21 (6.0-8.0)	1,000	1,400	na	140	No	No
Metals								
Antimony	0.366	B3	3.6	41	na	3.6	Yes	No
Arsenic	17.6	SB-101 (0.0 - 2.0)	3.9	4.5	na	0.45	Yes	Yes
Barium	103	5/30/2001 at B-3	1,100	20,300	na	1,100	No	No
Cadmium	0.469	5/30/2001 at B-3	5	79	na	5	No	No
Chromium, Total	50.9	SB-157 (0.0 - 2.0)	25	300	na	25	Yes	Yes
Copper	52.4	SB-140 (3.0 - 5.0)	460	4,100	na	410	Yes	No
Iron	29000	SB-101 (0.0 - 2.0)	640	55,000	na	640	Yes	Yes
Lead	7.48	5/30/2001 at B-3	na	400	na	40	No	No
Mercury	<0.0418	3/8/2001 at MW135	1.4	30	18	1.4	No	No
Nickel	38	SB-118 (2.0 - 3.7)	8.6	2,000	na	8.6	Yes	Yes
Selenium	0.635	SB-140 (3.0 - 5.0)	3.4	510	na	3.4	Yes	No
Silver	0.107	B3	11.2	510	na	11.2	No	No
Zinc	83.7	SB-140 (3.0 - 5.0)	4,100	30,400	na	3,040	Yes	No
Other								
Alkanol amines	--		na	na	na	na	Yes[o]	Yes[o]
Alkylamines	--		na	na	na	na	Yes[o]	Yes[o]
Alkylene amines	--		na	na	na	na	Yes[o]	Yes[o]
Calcium	--						No[l]	No[l]
Chloride	--						No[l]	No[l]
Dinonylnaphthylsulfonic acid	--		na	na	na	na	Yes[o]	Yes[o]
Fluoroalkyl Surfactant	--		na	na	na	na	Yes[o]	Yes[o]
Heavy aromatic naptha (Naphtha, High Flash Aromatic [HFAN])	--						No[m]	No[m]
Heavy paraffinic distillate (mixture)	--						No[m]	No[m]
Iron Oxides	--		na	na	na	na	Yes[o]	Yes[o]
2-Methoxymethylethoxy propanol	--		na	na	na	na	Yes[o]	Yes[o]
Monoethanolamine	--		na	na	na	na	Yes[o]	Yes[o]
Montmorillonite, calcined	--		na	na	na	na	Non	Non
Silica	--		na	na	na	na	Yes[o]	Yes[o]
Cyanide	0.15	SB-101 (0.0 - 2.0)	27	2,000	na	27	Yes[o]	No
Sulfate	--		na	na	na	na	No [j]	No [j]
Sulfolane	58.9	O-2	0.073	250	na	0.073	Yes	Yes
GRO	7,730	3/8/2001 at MW135	300	1,400	1,400	140	Yes	Yes
DRO	18800	SB-160 (6.4-8.4)	250	10,250	12,500	250	Yes	Yes
RRO	64700	1236-072804-009	11,000	10,000	22,000	1,000	Yes	Yes

Table 3-2a
Constituents of Potential Concern in Soil and Groundwater

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Constituents of Interest	Maximum Groundwater Concentration (ug/L) [d,k]	Maximum Observation or MRL Location	ADEC Groundwater Screening Level (ug/L)	Source	Groundwater COPC in RAWP [b]	Groundwater COPC in 2012 HHRA [c]
VOCs						
1,1-Dichloroethene	<16.96	MW-125 & Dup	0.7	[e]	Yes	Yes
1,2,4-Trimethylbenzene	614	MW-139 & Dup	180	[e]	Yes	Yes
1,3,5-Trimethylbenzene	184	MW-139 & Dup	180	[e]	Yes	Yes
1-Chloronaphthalene	<21.3	11/17/2006 at MW-106	290	[f]	No[i]	No[i]
4-Isopropyltoluene (p-cymene)	60.4	MW-139 & Dup	na		Yes	Yes
Benzene	18500	MW-135	0.5	[e]	Yes	Yes
Chlorobenzene	< 1 - <400	04/17/2007 at MW-138	10	[e]	No	No
cis-1,2-Dichloroethene	2.84	5/10/2001 at MW-116	7	[e]	No	No
Cyclohexane	542	MW-125 & Dup	1,300	[f]	Yes	No
Ethylbenzene	2750	MW-135	70	[e]	Yes	Yes
Isopropylbenzene (cumene)	106	5/10/2001 at MW-116	370	[e]	No	No
Methyl tert-butyl ether	7.1	MW-127 & Dup	47	[e]	Yes	No
Methylene chloride	<12.16	MW-125 & Dup	0.5	[e]	Yes	Yes
n-Butylbenzene	14.3	5/10/2001 at MW-116	37	[e]	No	No
n-Hexane	64.8	MW-135	88	[f]	Yes	No
n-Propylbenzene	122	MW-139 & Dup	37	[e]	Yes	Yes
Propylene gylcol (1,2,-Propanediol)	<2000	MW-110	73,000	[f]	Yes	No
Pyridine	<21.3	11/17/2006 at MW-106	3.7	[f]	No[i]	No[i]
sec-Butylbenzene	18.6	5/10/2001 at MW-116	37	[e]	No	No
tert-Butylbenzene	<0.002	5/10/2001 at MW-116	37	[e]	No	No
Toluene	30100	MW-135	100	[e]	Yes	Yes
Trichlorofluoromethane (Freon 11)	<2	2001 all MWs analyzed	1,100	[e]	No	No
Xylenes	14,090	MW-135	1,000	[e]	Yes	Yes
SVOCs						
1,2-Dichlorobenzene	1.4	04/17/2007 at MW-116	60	[e]	No	No
1,2-Diphenylhydrazine (as Azobenzene)	<21.3	11/17/2006 at MW-106	0.084	[f]	No[i]	No[i]
1,3-Dichlorobenzene	< 1-< 400	04/17/2007 at MW-138	330	[e]	No	No
1-Methylnaphthalene	35	MW-139 & Dup	15	[e]	Yes	Yes
2,4,5-Trichlorophenol	<10.6	11/17/2006 at MW-106	370	[e]	No	No
2,4,6-Trichlorophenol	<10.6	11/17/2006 at MW-106	7.7	[e]	No[i]	No[i]
2,4-Dichlorophenol	<10.6	11/17/2006 at MW-106	11	[e]	No	No
2,4-Dimethylphenol	22	5/10/2001 at MW-116	73	[e]	No	No
2,4-Dinitrophenol	<21.3	11/17/2006 at MW-106	7.3	[e]	No[i]	No[i]
2,4-Dinitrotoluene	<10.6	11/17/2006 at MW-106	0.13	[e]	No[i]	No[i]
2,6-Dinitrotoluene	<10.6	11/17/2006 at MW-106	0.13	[e]	No[i]	No[i]
2-Chloronaphthalene	<10.6	11/17/2006 at MW-106	290	[f]	No	No
2-Chlorophenol	<10.6	11/17/2006 at MW-106	18	[e]	No	No
2-Methylnaphthalene	30.9	MW-139 & Dup	15	[e]	Yes	Yes
2-Methylphenol (o-Cresol)	<10.6	11/17/2006 at MW-106	180	[e]	No	No
2-Nitroaniline	<21.3	11/17/2006 at MW-106	37	[f]	No	No
2-Nitrophenol	<10.6	11/17/2006 at MW-106	na		No[i]	No[i]
3 & 4-Methylphenol (m,p-Cresol)	<10.6	11/17/2006 at MW-106	18	[e]	No	No
3,3-Dichlorobenzidine	<21.3	11/17/2006 at MW-106	0.19	[e]	No[i]	No[i]
3-Nitroaniline	<10.6	11/17/2006 at MW-106	na		No[i]	No[i]
4,6-Dinitro-2-methylphenol	<10.6	11/17/2006 at MW-106	na		No[i]	No[i]
4-Bromophenyl phenyl ether	<10.6	11/17/2006 at MW-106	na		No[i]	No[i]
4-Chloro-3-methylphenol	<10.6	11/17/2006 at MW-106	na		No[i]	No[i]
4-Chloroaniline	<10.6	11/17/2006 at MW-106	1.6	[e]	No[i]	No[i]
4-Chlorophenyl phenyl ether	<10.6	11/17/2006 at MW-106	na		No[i]	No[i]
4-Nitroaniline	<10.6	11/17/2006 at MW-106	3.4		No[i]	No[i]
4-Nitrophenol	<10.6	11/17/2006 at MW-106	na		No[i]	No[i]
Acenaphthene	<0.0588	MW-106	220	[e]	No	No
Acenaphthylene	<0.0588	MW-106	220	[e]	No	No
Anthracene	<0.0588	MW-106	1,100	[e]	No	No
Benzidine	<21.3	11/17/2006 at MW-106	0.000094	[f]	No[i]	No[i]
Benzo (a) anthracene	<0.0588	MW-106	0.12	[e]	Yes	No [k]
Benzo (a) pyrene	<0.0588	MW-106	0.012	[e]	Yes	No [k]
Benzo (b) fluoranthene	<0.0588	MW-106	0.12	[e]	Yes	No [k]
Benzo (g,h,i) perylene	<0.0588	MW-106	110	[e]	No	No
Benzo (k) fluoranthene	<0.0588	MW-106	1.2	[e]	Yes	No [k]
Benzoic Acid	< 106	11/17/2006 at MW-106	15,000	[e]	No	No
Benzyl alcohol	<10.6	11/17/2006 at MW-106	370	[f]	No	No
Bis(2-chloroethoxy)methane	<10.6	11/17/2006 at MW-106	11	[f]	No	No
Bis(2-chloroethyl)ether	<10.6	11/17/2006 at MW-106	0.077	[e]	No[i]	No[i]
Bis(2-chloroisopropyl)ether	<10.6	11/17/2006 at MW-106	na		No	No
Bis(2-ethylhexyl)phthalate	< 53.2	11/17/2006 at MW-106	0.6	[e]	No[i]	No[i]
Butyl benzyl phthalate	<10.6	11/17/2006 at MW-106	730	[e]	No	No
Carbazole	<10.6	11/17/2006 at MW-106	4.3	[e]	No[i]	No[i]
Chrysene	<0.0588	MW-106	12	[e]	No	No [k]
Dibenzo (a,h) anthracene	<0.0588	MW-106	0.012	[e]	Yes	No [k]

Table 3-2a
Constituents of Potential Concern in Soil and Groundwater

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Constituents of Interest	Maximum Groundwater Concentration (ug/L) [d,k]	Maximum Observation or MRL Location	ADEC Groundwater Screening Level (ug/L)	Source	Groundwater COPC in RAWP [b]	Groundwater COPC in 2012 HHRA [c]
Dibenzofuran	<6.4	MW-135	7.3	[e]	Yes	No
Diethyl phthalate	<10.6	11/17/2006 at MW-106	2,900	[e]	No	
Dimethyl phthalate	<10.6	11/17/2006 at MW-106	37,000	[e]	No	No
Di-n-butyl phthalate	<10.6	11/17/2006 at MW-106	na		No[i]	No[i]
Di-n-Octylphthalate	12	5/10/2001 at MW-225	150	[e]	No	No
Fluoranthene	<0.0588	MW-106	150	[e]	No	No
Fluorene	<0.0588	MW-106	150	[e]	No	No
Hexachlorobenzene	<10.6	11/17/2006 at MW-106	0.1	[e]	No [i]	No
Hexachlorobutadiene	<10.6	11/17/2006 at MW-106	0.73	[e]	No [i]	No
Hexachlorocyclopentadiene	<10.6	11/17/2006 at MW-106	5	[e]	No [i]	No
Hexachloroethane	<10.6	11/17/2006 at MW-106	4	[e]	No [i]	No
Indeno (1,2,3-cd) pyrene	<0.0588	MW-106	0.12	[e]	Yes	No [k]
Isophorone	<10.6	11/17/2006 at MW-106	90	[e]	No	No
Isopropanol (propanol)	<400	MW-113	na		Yes	Yes
Naphthalene	300	MW-139 & Dup	73	[e]	Yes	Yes
Nitrobenzene	<10.6	11/17/2006 at MW-106	1.8	[e]	No [i]	No [i]
N-Nitrosodimethylamine	<21.3	11/17/2006 at MW-106	0.0017	[e]	No [i]	No [i]
N-Nitrosodi-n-propylamine	<10.6	11/17/2006 at MW-106	0.012	[e]	No [i]	No [i]
N-Nitrosodiphenylamine	<10.6	11/17/2006 at MW-106	17	[e]	No	No
Pentachlorophenol	<10.6	11/17/2006 at MW-106	0.1	[e]	No [i]	No [i]
Phenanthrene	<0.0588	MW-106	1,100	[e]	No	No
Phenol	<10.6	11/17/2006 at MW-106	1,100	[e]	No	No
Pyrene	<0.0588	MW-106	110	[e]	No	No
Metals						
Antimony	0.389	MW-110	0.6	[e]	Yes	No
Arsenic	68.5	5/10/2001 at MW-116	1	[e]	No [j]	No [j]
Barium	481	MW-110	200	[e]	Yes	Yes
Cadmium	<1.2	MW-110	0.5	[c]	Yes	Yes
Chromium, Total	3	MW-110	10	[e]	Yes	No
Copper	9.07	MW-149A	100	[e]	No	No
Iron	56,900	MW-110	2,600	[f]	Yes	Yes
Lead	2.05	MW-110	1.5	[e]	Yes	Yes
Mercury	<0.2	2001 all MWs analyzed	0.2	[e]	No	No
Nickel	9.57	3/4/2011 at MW-171A	10	[e]	No	No
Selenium	2.86	MW-141	5	[e]	Yes	No
Silver	5.02	5/10/2001 at MW-115	10	[e]	No	No
Zinc	9.17	3/8/2011 MW-171A	500	[e]	No	No
Other						
Alkanol amines	--		na		Yes[o]	Yes[o]
Alkylamines	--		na		Yes[o]	Yes[o]
Alkylene amines	--		na		Yes[o]	Yes[o]
Calcium	--		na		No[l]	No[l]
Chloride	--		na		No[l]	No[l]
Dinonylnaphthylsulfonic acid	--		na		Yes[o]	Yes[o]
Fluoroalkyl Surfactant	--		na		Yes[o]	Yes[o]
Heavy aromatic naptha (Naphtha, High Flash Aromatic [HFAN])	--		na		No[m]	No[m]
Heavy paraffinic distillate (mixture)	--		na		No[m]	No[m]
Iron Oxides	--		na		Yes[o]	Yes[o]
2-Methoxymethylethoxy propanol	--		na		Yes[o]	Yes[o]
Monoethanolamine	--		na		Yes[o]	Yes[o]
Montmorillonite, calcined	--		na		No[n]	No[n]
Silica	--		na		Yes[o]	Yes[o]
Cyanide	5.6	MW-125	20	[e]	Yes[o]	No
Sulfate	38600	MW-131	na		No [j]	No [j]
Sulfolane	10400	O-1	5	[e]	Yes	Yes
GRO	20800	MW-135	220	[e]	Yes	Yes
DRO	2150	MW-110	150	[e]	Yes	Yes
RRO	278	MW-135	110	[e]	Yes	Yes

Table 3-2a
Constituents of Potential Concern in Soil and Groundwater

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Notes:
"mg/kg" = milligrams per kilogram.
"µg/L" = micrograms per liter.
"ADEC" = Alaska Department of Environmental Conservation.
"BaP TEQ" = benzo(a) pyrene toxicty equivalent
"COPC" = constituent of potential concern
"DRO" = Total petroleum hydrocarbons diesel range organics = DRO
"GRO" = Total petroleum hydrocarbons gasoline range organics = GRO
"MDL" = method detection limit
"PAH" = polycyclic aromatic hydrocarbon
"RRO" = Total petroleum hydrocarbons residual range organics = RRO
"<" = not detected at the PQL indicated.
"--" = not analyzed.
"na" = not available.

[a] Values from the soil HHRA dataset (available electronically), plus maximum reporting limits from historical documents for non-detected compounds that were not analyzed in the HHRA dataset.
[b] As presented in Table 2 of the RAWP (ARCADIS, 2011).
[c] Revised COPC list selected based on the 2012 HHRA dataset and historical reporting limits, as presented in this table. The following rules were used to select COPCs:
1. If the maximum detected concentration exceeds the selected screening level, the constituent is retained as a COPC
2. If the maximum reporting limit exceeds the selected screening level, the constituent is retained as a COPC
3. If no screening level is available, the constituent is retained as a COPC
4. Constituents not included in the ingredient list but analyzed in soil or groundwater as part of full-scan VOC analyses were excluded as COPCs if never detected above the MDL.
5. Constituents detected within range of regional background levels were not selected as a COPC (USGS Fact Sheet FS-111-01)
6. PAHs included in the BaP TEQ calculation are included as COPCs if BaP TEQ is a COPC.
[d] Values from the onsite groundwater dataset (2009-2011) used in the 2012 HHRA.
[e] ADEC 2009 Table C Method Two groundwater cleanup level modified to 1E-6 target risk or 0.1 hazard quotient
[f] USEPA (2011) Regional Screening Level modified to 1E-6 target risk or 0.1 hazard quotient.
[g] SWI 2010, Table 3
[h] Based on the lowest of: migration to groundwater CUL, or 1/10th of the direct contact or outdoor inhalation CUL, provided in Tables B1 and B2 of 18 AAC75
[i] COI not included on ingredient list, but was analyzed in soil and/or groundwater as part of full-scan VOC analyses. Not selected as COPC because constituent was not detected above the MDL.
[j] concentrations within range of regional background levels, not selected as a COPC (USGS Fact Sheet FS-111-01)
[k] Included in Benzo(a)pyrene TEQ calculation
[l] ubiquitous in natural waters, not selected as a COPC
[m] compound is a petroleum distillate composed of several individual substances, not selected as a COPC
[n] this is a type of clay, not selected as a COPC
[o] subject to further discussion with ADEC
The USEPA (2010) Regional Screening Level Tables were the source of screening levels for 1,2-Diphenylhydrazine (as Azobenzene), and Benzidine
The USEPA (2010) Regional Screening Level Tables were adjusted for a hazard index of 0.1 for non-cancer screening levels for 1-Chloronaphthalene, 2-Chloronaphthalene, 2-Nitroaniline, Benzyl alcohol, Bis(2-chloroethoxy)methane, Cyclohexane, h-Hexane, Iron, Propylene glycol, and Pyridine.
Sulfolane values based on calculations provided in ADEC (2008) Cleanup Level Guidance
USEPA = United States Environmental Protection Agency Integrated Risk Information System (2011)

Table 3-2b
Summary of Constituents of Potential Concern

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	Surface Soil COPC [a,b]	Surface and Subsurface Soil COPC [a,c]	Soil Gas COPC [d]	Onsite Groundwater COPC [a,e]	Sitewide COPC [a]	Offsite COPC [a]
Metals						
Antimony	N	N	N	N	N	N
Arsenic	Y	Y	--	--	Y	N
Barium	--	N	N	Y	Y	N
Cadmium	--	N	N	Y	Y	N
Chromium, Total	Y	Y	N	N	Y	N
Copper	N	N	N	N	N	N
Iron	Y	Y	N	Y	Y	N
Lead	--	N	N	Y	Y	N
Mercury	--	N	--	--	N	N
Nickel	Y	Y	--	--	Y	N
Selenium	N	N	N	N	N	N
Silver	--	N	--	--	N	N
Zinc	N	N	--	--	N	N
VOCs						
1,1-Dichloroethene	Y	Y	Y	Y	Y	N
1,2,4-Trimethylbenzene	Y	Y	Y	Y	Y	N
1,3,5-Trimethylbenzene	Y	Y	Y	Y	Y	N
1-Chloronaphthalene	--	--	--	--	N	N
4-Isopropyltoluene (p-cymene)	Y	Y	Y	Y	Y	N
Benzene	Y	Y	Y	Y	Y	N
Chlorobenzene	Y	Y	--	--	Y	N
cis-1,2-Dichloroethene	Y	Y	--	--	Y	N
Cyclohexane	Y	Y	N	N	Y	N
Ethylbenzene	Y	Y	Y	Y	Y	N
Isopropylbenzene (cumene)	Y	Y	--	--	Y	N
Methyl tert-butyl ether	Y	Y	N	N	Y	N
Methylene chloride	Y	Y	Y	Y	Y	N
n-Butylbenzene	Y	Y	--	--	Y	N
n-Hexane	Y	Y	N	N	Y	N
n-Propylbenzene	Y	Y	Y	Y	Y	N
Propylene gylcol (1,2,-Propanediol)	--	--	N	N	N	N
Pyridine	--	--	--	--	N	N
sec-Butylbenzene	--	Y	--	--	Y	N
tert-Butylbenzene	N	N	--	--	N	N
Toluene	Y	Y	Y	Y	Y	N
Trichlorofluoromethane (Freon 11)	--	N	--	--	N	N
Xylenes	Y	Y	Y	Y	Y	N
SVOCs						
1,2-Dichlorobenzene	Y	Y	--	--	Y	N
1,2-Diphenylhydrazine (as Azobenzene)	--	--	--	--	N	N
1,3-Dichlorobenzene	Y	Y	--	--	Y	N
1-Methylnaphthalene	Y	Y	Y	Y	Y	N
2,4,5-Trichlorophenol	--	--	--	--	N	N
2,4,6-Trichlorophenol	Y	Y	--	--	Y	N
2,4-Dichlorophenol	Y	Y	--	--	Y	N
2,4-Dimethylphenol	Y	Y	--	--	Y	N
2,4-Dinitrophenol	Y	Y	--	--	Y	N
2,4-Dinitrotoluene	Y	Y	--	--	Y	N
2,6-Dinitrotoluene	Y	Y	--	--	Y	N
2-Chloronaphthalene	--	--	--	--	N	N
2-Chlorophenol	Y	Y	--	--	Y	N
2-Methylnaphthalene	Y	Y	Y	Y	Y	N
2-Methylphenol (o-Cresol)	Y	Y	--	--	Y	N
2-Nitroaniline	--	--	--	--	N	N
2-Nitrophenol	--	--	--	--	N	N
3 & 4-Methylphenol (m,p-Cresol)	Y	Y	--	--	Y	N
3,3-Dichlorobenzidine	Y	Y	--	--	Y	N
3-Nitroaniline	--	--	--	--	N	N
4,6-Dinitro-2-methylphenol	N	N	--	--	N	N
4-Bromophenyl phenyl ether	--	--	--	--	N	N
4-Chloro-3-methylphenol	--	--	--	--	N	N
4-Chloroaniline	Y	Y	--	--	Y	N
4-Chlorophenyl phenyl ether	--	--	--	--	N	N
4-Nitroaniline	--	--	--	--	N	N
4-Nitrophenol	--	--	--	--	N	N
Benzidine	--	--	--	--	N	N
Benzoic Acid	N	N	--	--	N	N
Benzyl alcohol	N	N	--	--	N	N
Bis(2-chloroethoxy)methane	N	N	--	--	N	N
Bis(2-chloroethyl)ether	Y	Y	--	--	Y	N
Bis(2-chloroisopropyl)ether	--	--	--	--	N	N
Bis(2-ethylhexyl)phthalate	N	N	--	--	N	N
Butyl benzyl phthalate	N	N	--	--	N	N
Carbazole	--	--	--	--	N	N

Table 3-2b
Summary of Constituents of Potential Concern

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	Surface Soil COPC [a,b]	Surface and Subsurface Soil COPC [a,c]	Soil Gas COPC [d]	Onsite Groundwater COPC [a,e]	Sitewide COPC [a]	Offsite COPC [a]
Dibenzofuran	N	N	N	N	N	N
Diethyl phthalate	N	N	--	--	N	N
Dimethyl phthalate	--	--	--	--	N	N
Di-n-butyl phthalate	N	N	--	--	N	N
Di-n-Octylphthalate	--	--	--	--	N	N
Hexachlorobenzene	Y	Y	--	--	Y	N
Hexachlorobutadiene	Y	Y	--	--	Y	N
Hexachlorocyclopentadiene	Y	Y	--	--	Y	N
Hexachloroethane	Y	Y	--	--	Y	N
Isophorone	Y	Y	--	--	Y	N
Isopropanol (propanol)	--	--	N	Y	Y	N
Nitrobenzene	Y	Y	--	--	Y	N
N-Nitrosodimethylamine	Y	Y	--	--	Y	N
N-Nitrosodi-n-propylamine	Y	Y	--	--	Y	N
N-Nitrosodiphenylamine	Y	Y	--	--	Y	N
Pentachlorophenol	Y	Y	--	--	Y	N
Phenol	N	N	--	--	N	N
PAHs						
Acenaphthene	N	N	N	N	N	N
Acenaphthylene	N	N	N	N	N	N
Anthracene	N	N	N	N	N	N
Benzo (a) anthracene	Y	Y	N	N	Y	N
Benzo (a) pyrene	Y	Y	N	N	Y	N
Benzo (b) fluoranthene	Y	Y	N	N	Y	N
Benzo (g,h,i) perylene	N	N	N	N	N	N
Benzo (k) fluoranthene	Y	Y	N	N	Y	N
Chrysene	Y	Y	N	N	Y	N
Dibenzo (a,h) anthracene	Y	Y	N	N	Y	N
Fluoranthene	N	N	N	N	N	N
Fluorene	N	N	N	N	N	N
Indeno (1,2,3-cd) pyrene	Y	Y	N	N	Y	N
Naphthalene	Y	Y	Y	Y	Y	N
Phenanthrene	N	N	N	N	N	N
Pyrene	N	N	N	N	N	N
Total Benzo(a)pyrene TEQ	Y	Y	N	N	Y	N
Miscellaneous						
Alkanol amines	--	--	--	--	N	N
Alkylamines	--	--	--	--	N	N
Alkylene amines	--	--	--	--	N	N
Calcium	--	--	--	--	N	N
Chloride	--	--	--	--	N	N
Dinonylnaphthylsulfonic acid	--	--	--	--	N	N
Fluoroalkyl Surfactant	--	--	--	--	N	N
Heavy aromatic naptha (Naphtha, High Flash Aromatic [HFAN])	--	--	--	--	N	N
Heavy paraffinic distillate (mixture)	--	--	--	--	N	N
Iron Oxides	--	--	--	--	N	N
2-Methoxymethylethoxy propanol	--	--	--	--	N	N
Monoethanolamine	--	--	--	--	N	N
Montmorillonite, calcined	--	--	--	--	N	N
Silica	--	--	--	--	N	N
Cyanide	N	N	N	N	N	N
Sulfate	--	--	N	N	N	N
Sulfolane	Y	Y	N	Y	Y	Y
GRO	Y	Y	N	Y	Y	N
DRO	Y	Y	N	Y	Y	N
RRO	Y	Y	N	Y	Y	N

Notes:

[a] COPCs are defined as described in the main text and in Table 3-2a.
[b] Soil data from the 0 to 2.5 ft bgs interval was used to evaluate exposure to surface soil.
[c] Soil data from the 0 to 15.5 ft bgs interval was used to evaluate exposure to surface and subsurface soil.
[d] Volatile compounds selected as groundwater COPCs were selected as soil gas COPCs.
[e] Groundwater data from the most recent two years of sampling (2009 through 2011) for wells without LNAPL were used to evaluate exposure to groundwater.
bgs = below ground surface
COPC = constituent of potential concern
FOD = frequency of detection
TEQ = toxicity equivalents
PAH = polycyclic aromatic hydrocarbon
VOC = volatile organic compound
N = no; Constituent is not a COPC
Y = yes; Constituent is a COPC
-- = no data available; Constituent is not a COPC

Table 3-3
Area-Wide Summary Statistics and UCL Exposure Point Concentrations for Surface Soil (0 to 2 ft below ground surface)

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

COPC [a]	Sample Size	Number of Detects	FOD (%) [b]	Min [c]	Max [c]	Mean [c]	Median [c]	SD	UCL Method	UCL	EPC [d]
Metals											
Arsenic	26	26	100	2.45	17.6	6.386	5.095	3.501	95% Approximate Gamma UCL	7.601	7.6E+00
Chromium, Total	26	26	100	8.83	50.9	16.99	14.9	8.051	95% Approximate Gamma UCL	19.39	1.9E+01
Iron	26	26	100	7790	29000	15081	12900	5471	95% Approximate Gamma UCL	16960	1.7E+04
Nickel	26	26	100	11.2	28.5	18.63	18.05	4.884	95% Student's-t UCL	20.27	2.0E+01
VOCs											
1,3,5-Trimethylbenzene	26	2	8	0.0141	0.0223	0.0182	0.0182	0.0058	--	--	2.2E-02
4-Isopropyltoluene (p-cymene)	26	2	8	0.0118	0.0182	0.015	0.015	0.00453	--	--	1.8E-02
Benzene	104	26	25	0.00243	0.597	0.0664	0.00937	0.135	95% Chebyshev (Mean, Sd) UCL	0.0508	5.1E-02
Cyclohexane	26	5	19	0.00949	0.1	0.0306	0.0129	0.0391	95% Chebyshev (Mean, Sd) UCL	0.0293	2.9E-02
Ethylbenzene	104	20	19	0.00544	2.36	0.374	0.0196	0.68	95% Chebyshev (Mean, Sd) UCL	0.218	2.2E-01
Methylene chloride	26	3	12	0.0286	0.0604	0.0477	0.0541	0.0168	--	--	6.0E-02
n-Hexane	26	4	15	0.0131	0.116	0.0532	0.0419	0.0486	--	--	1.2E-01
Toluene	104	19	18	0.00663	1.04	0.131	0.0217	0.254	95% Chebyshev (Mean, Sd) UCL	0.0815	8.2E-02
Xylenes	104	25	24	0.0161	10.3	0.935	0.0572	2.26	95% Chebyshev (Mean, Sd) UCL	0.739	7.4E-01
SVOCs											
1-Methylnaphthalene	104	23	22	0.0019	3.21	0.349	0.05	0.747	95% Chebyshev (Mean, Sd) UCL	0.242	2.4E-01
2-Methylnaphthalene	104	25	24	0.00182	3.66	0.356	0.0266	0.836	95% Chebyshev (Mean, Sd) UCL	0.274	2.7E-01
PAHs											
Benzo (a) anthracene	104	2	2	0.0241	0.0605	0.0423	0.0423	0.0257	--	--	6.1E-02
Benzo (a) pyrene	104	2	2	0.0311	0.0924	0.0618	0.0618	0.0433	--	--	9.2E-02
Benzo (b) fluoranthene	104	9	9	0.00173	0.108	0.0184	0.00282	0.0358	95% Chebyshev (Mean, Sd) UCL	0.0155	1.6E-02
Benzo (k) fluoranthene	104	2	2	0.0132	0.0404	0.0268	0.0268	0.0192	--	--	4.0E-02
Chrysene	104	18	17	0.00201	0.783	0.118	0.0249	0.214	95% Chebyshev (Mean, Sd) UCL	0.0659	6.6E-02
Dibenzo (a,h) anthracene	104	1	1	0.0171	0.0171	0.0171	0.0171	N/A	--	--	1.7E-02
Indeno (1,2,3-cd) pyrene	104	3	3	0.00161	0.0688	0.029	0.0165	0.0353	--	--	6.9E-02
Naphthalene	104	18	17	0.00176	0.631	0.106	0.0113	0.182	95% Chebyshev (Mean, Sd) UCL	0.0592	5.9E-02
Total Benzo(a)pyrene TEQ	104	24	23	0.00356	0.225	0.0383	0.0178	0.0578	95% Chebyshev (Mean, Sd) UCL	0.0317	3.2E-02

Table 3-3
Area-Wide Summary Statistics and UCL Exposure Point Concentrations for Surface Soil (0 to 2 ft below ground surface)

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

COPC [a]	Sample Size	Number of Detects	FOD (%) [b]	Min [c]	Max [c]	Mean [c]	Median [c]	SD	UCL Method	UCL	EPC [d]
Miscellaneous											
Sulfolane	99	3	3	0.00515	0.0377	0.0188	0.0135	0.0169	--	--	3.8E-02
GRO	26	4	15	0.604	5.35	2.216	1.456	2.204	--	--	5.4E+00
DRO	26	17	65	7.65	869	93.16	25.9	206.7	95% Chebyshev (Mean, Sd) UCL	209.1	2.1E+02
RRO	26	22	85	19.6	8450	524.7	71	1785	95% Chebyshev (Mean, Sd) UCL	1853	1.9E+03

Notes:

[a] COPCs are defined as described in the main text and Table 3-2a.

[b] FOD is based on inclusion of some historical data for which only detected concentrations are reported. FOD is not considered accurate for the entire dataset.

[d] The EPC is defined as the 95% UCL calculated using ProUCL v. 4.00.05.

[c] Minimum, maximum, mean, and median concentrations are based on detected concentrations.

The maximum detected concentration was used to represent the EPC when fewer than five detected concentrations and eight samples were available.

All concentrations are in units of mg/kg.

BCA = bias corrected accelerated
COPC = constituent of potential concern
DRO = Diesel range organics
EPC = exposure point concentration
FOD = frequency of detection
GRO = Gasoline range organics
KM = Kaplan-Meier
mg/kg = milligram(s) per kilogram
N/A = not available; insufficient data
PAH = polycyclic aromatic hydrocarbon
RRO = Residual range organics
TEQ = toxicity equivalents
SD = standard deviation
SVOCs = semi-volatile organic compounds
UCL = upper confidence limit on the mean
VOCs = volatile organic compounds

Table 3-4a
Area-Wide Summary Statistics and Maximum Exposure Point Concentrations for Subsurface Soil (0 to 15 ft below ground surface)

Human Health Risk Assessment - PPRTV Scenario and ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

COPC [a]	Sample Size	Number of Detects	FOD (%) [b]	Min [c]	Max [c]	Mean [c]	Median [c]	SD	UCL Method	UCL	EPC [d]
Metals											
Arsenic	69	69	100	2.16	17.6	5.525	4.18	3.406	95% Chebyshev (Mean, Sd) UCL	7.313	1.8E+01
Chromium, Total	69	69	100	7.69	50.9	15.84	13.9	7.03	95% Approximate Gamma UCL	17.15	5.1E+01
Iron	62	62	100	7330	29000	13815	11450	5719	95% Modified-t UCL	15048	2.9E+04
Nickel	62	62	100	8.88	38	17.58	15.7	6.458	95% Approximate Gamma UCL	18.94	3.8E+01
VOCs											
1,2,4-Trimethylbenzene	90	26	29	0.0567	205	30.46	13.6	47.56	95% Chebyshev (Mean, Sd) UCL	22.03	2.1E+02
1,3,5-Trimethylbenzene	89	27	30	0.0141	81.1	10.6	4.57	18.14	95% Chebyshev (Mean, Sd) UCL	8.31	8.1E+01
4-Isopropyltoluene (p-cymene)	90	24	27	0.0118	20.2	2.745	1.165	4.575	95% Chebyshev (Mean, Sd) UCL	2.026	2.0E+01
Benzene	318	122	38	0.00243	82	3.904	0.232	10.35	95% Chebyshev (Mean, Sd) UCL	3.131	8.2E+01
Cyclohexane	62	21	34	0.00949	44.9	5.395	0.0375	10.95	95% Chebyshev (Mean, Sd) UCL	5.585	4.5E+01
Ethylbenzene	318	122	38	0.00544	111	12.7	0.947	22.96	95% Chebyshev (Mean, Sd) UCL	8.659	1.1E+02
Isopropylbenzene (cumene)	90	24	27	0.0102	41.6	5.561	1.845	9.393	95% Chebyshev (Mean, Sd) UCL	3.96	4.2E+01
Methylene chloride	63	7	11	0.0282	0.188	0.0643	0.0541	0.0561	95% Chebyshev (Mean, Sd) UCL	0.29	1.9E-01
n-Butylbenzene	90	16	18	0.00998	107	11.72	3.34	26.79	95% Chebyshev (Mean, Sd) UCL	7.626	1.1E+02
n-Hexane	62	17	27	0.0126	13	3.024	0.116	4.717	95% Chebyshev (Mean, Sd) UCL	2.369	1.3E+01
n-Propylbenzene	90	23	26	0.0145	72.7	10.49	3.8	17.46	95% Chebyshev (Mean, Sd) UCL	7.203	7.3E+01
sec-Butylbenzene	28	11	39	0.162	25.3	5.162	2.25	7.488	95% Chebyshev (Mean, Sd) UCL	6.552	2.5E+01
Toluene	318	100	31	0.00659	392	24.38	0.654	67.73	95% Chebyshev (Mean, Sd) UCL	17.34	3.9E+02
Xylenes	318	132	42	0.0161	706	62.17	0.991	127.8	95% Chebyshev (Mean, Sd) UCL	47.25	7.1E+02
SVOCs											
1-Methylnaphthalene	287	123	43	0.00159	88.5	5.827	0.463	11.78	95% Chebyshev (Mean, Sd) UCL	4.614	8.9E+01
2-Methylnaphthalene	314	139	44	0.00159	240	9.68	0.711	25.24	95% Chebyshev (Mean, Sd) UCL	8.584	2.4E+02
PAHs											
Benzo (a) anthracene	287	14	5	0.00198	0.0988	0.0329	0.0279	0.0289	95% Chebyshev (Mean, Sd) UCL	0.0117	9.9E-02
Benzo (a) pyrene	287	13	5	0.00294	0.0952	0.0364	0.0283	0.0345	95% Chebyshev (Mean, Sd) UCL	0.0119	9.5E-02
Benzo (b) fluoranthene	287	20	7	0.00166	0.108	0.0216	0.00698	0.0316	95% Chebyshev (Mean, Sd) UCL	0.0206	1.1E-01
Benzo (k) fluoranthene	287	9	3	0.00214	0.0404	0.0132	0.011	0.013	95% Chebyshev (Mean, Sd) UCL	0.0194	4.0E-02
Chrysene	287	56	20	0.00201	0.783	0.0713	0.0234	0.142	95% Chebyshev (Mean, Sd) UCL	0.0354	7.8E-01
Dibenzo (a,h) anthracene	287	6	2	0.002	0.018	0.0104	0.0103	0.00718	95% Chebyshev (Mean, Sd) UCL	0.00988	1.8E-02
Indeno (1,2,3-cd) pyrene	287	12	4	0.00161	0.0688	0.0247	0.018	0.0224	95% Chebyshev (Mean, Sd) UCL	0.0109	6.9E-02
Naphthalene	314	132	42	0.00165	125	5.055	0.347	13.55	95% Chebyshev (Mean, Sd) UCL	4.371	1.3E+02
Total Benzo(a)pyrene TEQ	228	62	27	0.00356	0.225	0.0366	0.0179	0.0508	95% Chebyshev (Mean, Sd) UCL	0.0257	2.3E-01

Table 3-4a
Area-Wide Summary Statistics and Maximum Exposure Point Concentrations for Subsurface Soil (0 to 15 ft below ground surface)

Human Health Risk Assessment - PPRTV Scenario and ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

COPC [a]	Sample Size	Number of Detects	FOD (%) [b]	Min [c]	Max [c]	Mean [c]	Median [c]	SD	UCL Method	UCL	EPC [d]
Miscellaneous											
Sulfolane	277	70	25	0.00434	18.4	0.411	0.0496	2.204	95% Chebyshev (Mean, Sd) UCL	0.454	1.8E+01
GRO	76	28	37	0.604	7730	782.8	127	1611	95% Chebyshev (Mean, Sd) UCL	808.3	7.7E+03
DRO	106	71	67	7.65	18800	1546	226	2905	95% Chebyshev (Mean, Sd) UCL	2111	1.9E+04
RRO	121	89	74	0.162	64700	5042	108	13078	95% Chebyshev (Mean, Sd) UCL	8236	6.5E+04

Notes:

All concentrations are in units of mg/kg.

[a] COPCs are defined as described in the main text and Table 3-2a.

[b] FOD is based on inclusion of some historical data for which only detected concentrations are reported. FOD is not considered accurate for the entire dataset.

[c] Minimum, maximum, mean, and median concentrations are based on detected concentrations.

[d] The maximum detected concentration was used to represent the EPC.

BCA = bias corrected accelerated

COPC = constituent of potential concern

EPC = exposure point concentration

DRO = Diesel range organics

FOD = frequency of detection

GRO = Gasoline range organics

KM = Kaplan-Meier

mg/kg = milligram(s) per kilogram

N/A = not available; insufficient data

PAH = polycyclic aromatic hydrocarbon

RRO = Residual range organics

SD = standard deviation

SVOCs = semi-volatile organic compounds

TEQ = toxicity equivalents

TPH = total petroleum hydrocarbons

UCL = upper confidence limit on the mean

VOC = volatile organic compound

Table 3-4b
Area-Wide Summary Statistics and UCL Exposure Point Concentrations for Subsurface Soil (0 to 15 ft below ground surface)

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

COPC [a]	Sample Size	Number of Detects	FOD (%) [b]	Min [c]	Max [c]	Mean [c]	Median [c]	SD	UCL Method	UCL	EPC [d]
Metals											
Arsenic	69	69	100	2.16	17.6	5.525	4.18	3.406	95% Chebyshev (Mean, Sd) UCL	7.313	7.3E+00
Chromium, Total	69	69	100	7.69	50.9	15.84	13.9	7.03	95% Approximate Gamma UCL	17.15	1.7E+01
Iron	62	62	100	7330	29000	13815	11450	5719	95% Modified-t UCL	15048	1.5E+04
Nickel	62	62	100	8.88	38	17.58	15.7	6.458	95% Approximate Gamma UCL	18.94	1.9E+01
VOCs											
1,2,4-Trimethylbenzene	90	26	29	0.0567	205	30.46	13.6	47.56	95% Chebyshev (Mean, Sd) UCL	22.03	2.2E+01
1,3,5-Trimethylbenzene	89	27	30	0.0141	81.1	10.6	4.57	18.14	95% Chebyshev (Mean, Sd) UCL	8.31	8.3E+00
4-Isopropyltoluene (p-cymene)	90	24	27	0.0118	20.2	2.745	1.165	4.575	95% Chebyshev (Mean, Sd) UCL	2.026	2.0E+00
Benzene	318	122	38	0.00243	82	3.904	0.232	10.35	95% Chebyshev (Mean, Sd) UCL	3.131	3.1E+00
Cyclohexane	62	21	34	0.00949	44.9	5.395	0.0375	10.95	95% Chebyshev (Mean, Sd) UCL	5.585	5.6E+00
Ethylbenzene	318	122	38	0.00544	111	12.7	0.947	22.96	95% Chebyshev (Mean, Sd) UCL	8.659	8.7E+00
Isopropylbenzene (cumene)	90	24	27	0.0102	41.6	5.561	1.845	9.393	95% Chebyshev (Mean, Sd) UCL	3.96	4.0E+00
Methylene chloride	63	7	11	0.0282	0.188	0.0643	0.0541	0.0561	95% Chebyshev (Mean, Sd) UCL	0.29	2.9E-01
n-Butylbenzene	90	16	18	0.00998	107	11.72	3.34	26.79	95% Chebyshev (Mean, Sd) UCL	7.626	7.6E+00
n-Hexane	62	17	27	0.0126	13	3.024	0.116	4.717	95% Chebyshev (Mean, Sd) UCL	2.369	2.4E+00
n-Propylbenzene	90	23	26	0.0145	72.7	10.49	3.8	17.46	95% Chebyshev (Mean, Sd) UCL	7.203	7.2E+00
sec-Butylbenzene	28	11	39	0.162	25.3	5.162	2.25	7.488	95% Chebyshev (Mean, Sd) UCL	6.552	6.6E+00
Toluene	318	100	31	0.00659	392	24.38	0.654	67.73	95% Chebyshev (Mean, Sd) UCL	17.34	1.7E+01
Xylenes	318	132	42	0.0161	706	62.17	0.991	127.8	95% Chebyshev (Mean, Sd) UCL	47.25	4.7E+01
SVOCs											
1-Methylnaphthalene	287	123	43	0.00159	88.5	5.827	0.463	11.78	95% Chebyshev (Mean, Sd) UCL	4.614	4.6E+00
2-Methylnaphthalene	314	139	44	0.00159	240	9.68	0.711	25.24	95% Chebyshev (Mean, Sd) UCL	8.584	8.6E+00
PAHs											
Benzo (a) anthracene	287	14	5	0.00198	0.0988	0.0329	0.0279	0.0289	95% Chebyshev (Mean, Sd) UCL	0.0117	1.2E-02
Benzo (a) pyrene	287	13	5	0.00294	0.0952	0.0364	0.0283	0.0345	95% Chebyshev (Mean, Sd) UCL	0.0119	1.2E-02
Benzo (b) fluoranthene	287	20	7	0.00166	0.108	0.0216	0.00698	0.0316	95% Chebyshev (Mean, Sd) UCL	0.0206	2.1E-02
Benzo (k) fluoranthene	287	9	3	0.00214	0.0404	0.0132	0.011	0.013	95% Chebyshev (Mean, Sd) UCL	0.0194	1.9E-02
Chrysene	287	56	20	0.00201	0.783	0.0713	0.0234	0.142	95% Chebyshev (Mean, Sd) UCL	0.0354	3.5E-02
Dibenzo (a,h) anthracene	287	6	2	0.002	0.018	0.0104	0.0103	0.00718	95% Chebyshev (Mean, Sd) UCL	0.00988	9.9E-03
Indeno (1,2,3-cd) pyrene	287	12	4	0.00161	0.0688	0.0247	0.018	0.0224	95% Chebyshev (Mean, Sd) UCL	0.0109	1.1E-02
Naphthalene	314	132	42	0.00165	125	5.055	0.347	13.55	95% Chebyshev (Mean, Sd) UCL	4.371	4.4E+00
Total Benzo(a)pyrene TEQ	228	62	27	0.00356	0.225	0.0366	0.0179	0.0508	95% Chebyshev (Mean, Sd) UCL	0.0257	2.6E-02

Table 3-4b
Area-Wide Summary Statistics and UCL Exposure Point Concentrations for Subsurface Soil (0 to 15 ft below ground surface)

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

COPC [a]	Sample Size	Number of Detects	FOD (%) [b]	Min [c]	Max [c]	Mean [c]	Median [c]	SD	UCL Method	UCL	EPC [d]
Miscellaneous											
Sulfolane	277	70	25	0.00434	18.4	0.411	0.0496	2.204	95% Chebyshev (Mean, Sd) UCL	0.454	4.5E-01
GRO	76	28	37	0.604	7730	782.8	127	1611	95% Chebyshev (Mean, Sd) UCL	808.3	8.1E+02
DRO	106	71	67	7.65	18800	1546	226	2905	95% Chebyshev (Mean, Sd) UCL	2111	2.1E+03
RRO	121	89	74	0.162	64700	5042	108	13078	95% Chebyshev (Mean, Sd) UCL	8236	8.2E+03

Notes:

[a] COPCs are defined as described in the main text and Table 3-2.

[b] FOD is based on inclusion of some historical data for which only detected concentrations are reported. FOD is not considered accurate for the entire dataset.

[c] Minimum, maximum, mean, and median concentrations are based on detected concentrations.

[d] The EPC is defined as the 95% UCL calculated using ProUCL v. 4.00.05.

The maximum detected concentration was used to represent the EPC when fewer than five detected concentrations and eight samples were available.

All concentrations are in units of mg/kg.

BCA = bias corrected accelerated

COPC = constituent of potential concern

EPC = exposure point concentration

DRO = Diesel range organics

FOD = frequency of detection

GRO = Gasoline range organics

KM = Kaplan-Meier

mg/kg = milligram(s) per kilogram

N = no

N/A = not available; insufficient data

PAH = polycyclic aromatic hydrocarbon

RRO = Residual range organics

SD = standard deviation

SVOCs = semi-volatile organic compounds

TEQ = toxicity equivalents

TPH = total petroleum hydrocarbons

UCL = upper confidence limit on the mean

VOC = volatile organic compound

Y = yes

Table 3-5a
Area-Wide Summary Statistics and Maximum Exposure Point Concentrations for Onsite Groundwater (2009 through 2011)

Human Health Risk Assessment - PPRTV Scenario and ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

COCC [a]	Sample Size [b]	Number of Detects [b]	FOD (%)	Min [b]	Max [b]	Mean [b]	Median [b]	SD [b]	Groundwater EPC [c] (ug/L)	VF [d] (L/m^3)	Trench Air EPC [d] (ug/m^3)	Predicted Soil Gas Concentration [e] (ug/m^3)	AF [e]	Indoor Air EPC [e] (ug/m^3)
Metals														
Barium	19	19	100	39.3	481	193	182	124	4.8E+02					
Iron	19	15	79	1900	56900	13910	6090	16000	5.7E+04					
Lead	19	3	16	0.35	2.05	1.05	0.74	0.89052	2.1E+00					
VOCs														
1,2,4-Trimethylbenzene	62	16	26	4.35	614	128	57.3	177	6.1E+02	7.5E+00	4.6E+03	3.97E+04	1.12E-05	4.46E-01
1,3,5-Trimethylbenzene	19	7	37	1.93	184	50.7	21.2	64.2	1.8E+02	7.6E+00	1.4E+03	1.14E+04	1.27E-05	1.45E-01
4-Isopropyltoluene (p-cymene)	19	6	32	0.8	60.4	13.3	5.34	23.2	6.0E+01	7.2E+00	4.3E+02			
Benzene	330	148	45	0.17	18500	1802	91	3516	1.9E+04	9.3E+00	1.7E+05	1.66E+06	1.03E-05	1.72E+01
Ethylbenzene	330	97	29	0.44	2750	421	66.1	656	2.8E+03	8.0E+00	2.2E+04	2.74E+05	7.54E-06	2.07E+00
n-Propylbenzene	19	7	37	1	122	37.9	22.4	43.1	1.2E+02	7.6E+00	9.2E+02	1.42E+04	6.46E-06	9.18E-02
Toluene	330	58	18	0.39	30100	5715	2090	8395	3.0E+04	8.6E+00	2.6E+05	2.86E+06	8.71E-06	2.49E+01
Xylenes	330	122	37	0.57	14090	2097	424	3121	1.4E+04	8.0E+00	1.1E+05	1.35E+06	8.42E-06	1.14E+01
SVOCs														
1-Methylnaphthalene	10	6	60	0.0231	35	9.27	5.39	13.3	3.5E+01	6.3E+00	2.2E+02	1.10E+02	1.12E-04	1.22E-02
2-Methylnaphthalene	10	8	80	0.016	30.9	6.29	1.14	10.6	3.1E+01	6.3E+00	2.0E+02	9.67E+01	1.12E-04	1.08E-02
PAHs														
Naphthalene	29	9	31	0.0829	300	49.7	18.1	95.9	3.0E+02	6.6E+00	2.0E+03	1.31E+03	9.45E-05	1.24E-01
Miscellaneous														
Sulfolane	566	340	60	3.4	10400	251	105	634	1.0E+04	[f]	[f]	[f]	[f]	[f]
GRO	21	7	33	408	20800	4869	2110	7189	2.1E+04	N/A				
DRO	21	11	52	227	2150	1001	537	779	2.2E+03	N/A				
RRO	19	3	16	199	278	230	212	42.4	2.8E+02	N/A				

Notes:

All concentrations are in units of ug/L, unless noted otherwise.

[a] COPCs are defined as described in the main text and Table 3-2a.

[b] Statistics were calculated using the most recent two years of groundwater data (2009 through 2011) for all onsite wells without LNAPL.

[c] The maximum detected concentration was used to represent the EPC.

[d] Calculated using the Virginia Department of Environmental Quality Trench Air Model (VDEQ, 2012) for groundwater occurring at less than 15 feet below ground surface.

[e] Calculated using the Johnson & Ettinger Model for groundwater (DTSC, 2009). A commercial air exchange rate of 1 per hour was assumed.

[f] Sulfolane was not evaluated for inhalation pathways, as described in the RAWP (ARCADIS, 2011).

AF = Attenuation factor

COPC = constituent of potential concern

DRO = Diesel range organics

EPC = exposure point concentration

FOD = frequency of detection

GRO = Gasoline range organics

ug/L = microgram(s) per liter

ug/m^3 = microgram(s) per cubic meter

L/m^3 = liters per cubic meter

LNAPL = light non-aqueous phase liquid

N/A = not available; insufficient data

PAH = polycyclic aromatic hydrocarbon

RRO = Residual range organics

SD = standard deviation

SVOCs = semi-volatile organic compounds

TEQ = toxicity equivalents

UCL = upper confidence limit on the mean

VF = volatilization factor

VOC = volatile organic compound

Table 3-5b
Area-Wide Summary Statistics and UCL Exposure Point Concentrations for Onsite Groundwater (2009 through 2011)

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

COPC [a]	Sample Size [b]	Number of Detects [b]	FOD (%)	Min [b]	Max [b]	Mean [b]	Median [b]	SD [b]	UCL Method	UCL [b]	Groundwater EPC [a] (ug/L)	VF [e] (L/m^3)	Trench Air EPC [e] (ug/m^3)	Predicted Soil Gas Concentration [d] (ug/m^3)	AF [d]	Indoor Air EPC [d] (ug/m^3)
Metals																
Barium	19	19	100	39.3	481	193	182	124	95% Student's-t UCL	262	2.6E+02					
Iron	19	15	79	1900	56900	13910	6090	16000	95% Approximate Gamma UCL	28060	2.8E+04					
Lead	19	3	16	0.35	2.05	1.05	0.74	0.89052	Highest temporal average	1.18	1.2E+00					
VOCs																
1,2,4-Trimethylbenzene	62	16	26	4.35	614	128	57.3	177	95% Chebyshev (Mean, Sd) UCL	113	1.1E+02	7.5E+00	8.5E+02	7.31E+03	1.12E-05	8.20E-02
1,3,5-Trimethylbenzene	19	7	37	1.93	184	50.7	21.2	64.2	Highest temporal average	121	1.2E+02	7.6E+00	9.2E+02	7.48E+03	1.27E-05	9.50E-02
4-Isopropyltoluene (p-cymene)	19	6	32	0.8	60.4	13.3	5.34	23.2	Highest temporal average	33.4	3.3E+01	7.2E+00	2.4E+02			
Benzene	330	148	45	0.17	18500	1802	91	3516	95% Chebyshev(Mean, Sd) UCL	1334	1.3E+03	9.3E+00	1.2E+04	1.20E+05	1.03E-05	1.24E+00
Ethylbenzene	330	97	29	0.44	2750	421	66.1	656	95% Chebyshev (Mean, Sd) UCL	180	1.8E+02	8.0E+00	1.4E+03	1.80E+04	7.54E-06	1.35E-01
n-Propylbenzene	19	7	37	1	122	37.9	22.4	43.1	Highest temporal average	80.3	8.0E+01	7.6E+00	6.1E+02	9.36E+03	6.46E-06	6.04E-02
Toluene	330	58	18	0.39	30100	5715	2090	8395	95% Chebyshev (Mean, Sd) UCL	1427	1.4E+03	8.6E+00	1.2E+04	1.35E+05	8.71E-06	1.18E+00
Xylenes	330	122	37	0.57	14090	2097	424	3121	95% Chebyshev(Mean, Sd) UCL	1184	1.2E+03	8.0E+00	9.5E+03	1.13E+05	8.42E-06	9.55E-01
SVOCs																
1-Methylnaphthalene	10	6	60	0.0231	35	9.27	5.39	13.3	Highest temporal average	35	3.5E+01	6.3E+00	2.2E+02	1.10E+02	1.12E-04	1.22E-02
2-Methylnaphthalene	10	8	80	0.016	30.9	6.29	1.14	10.6	95% Hall's Bootstrap UCL	25.2	2.5E+01	6.3E+00	1.6E+02	7.88E+01	1.12E-04	8.81E-03
PAHs																
Naphthalene	29	9	31	0.0829	300	49.7	18.1	95.9	95% Hall's Bootstrap UCL	145	1.5E+02	6.6E+00	9.6E+02	6.35E+02	9.45E-05	6.00E-02
Miscellaneous																
Sulfolane	566	340	60	3.4	10400	251	105	634	95% Chebyshev (Mean, Sd) UCL	833	8.3E+02	[f]	[f]	[f]	[f]	[f]
GRO	21	7	33	408	20800	4869	2110	7189	Highest temporal average	20800	2.1E+04	N/A				
DRO	21	11	52	227	2150	1001	537	779	95% Chebyshev (Mean, Sd) UCL	1549	1.5E+03	N/A				
RRO	19	3	16	199	278	230	212	42.4	Highest temporal average	278	2.8E+02	N/A				

Notes:

[a] The EPC is defined as the 95% UCL calculated using ProUCL v. 4.00.05.

All concentrations are in units of ug/L, unless noted otherwise.

[b] Statistics were calculated using the most recent two years of groundwater data (2009 through 2011) for all onsite wells without LNAPL.

[a] COPCs are defined as described in the main text and Table 3-2.

COPC = constituent of potential concern

[d] Calculated using the Johnson & Ettinger Model for groundwater (DTSC, 2009). A commercial air exchange rate of 1 per hour was assumed.

[e] Calculated using the Virginia Department of Environmental Quality Trench Air Model (VDEQ, 2012) for groundwater occurring at less than 15 feet below ground surface.

[f] Sulfolane was not evaluated for inhalation pathways, as described in the RAWP (ARCADIS, 2011).

AF = Attenuation factor

EPC = exposure point concentration

DRO = Diesel range organics

FOD = frequency of detection

GRO = Gasoline range organics

ug/L = microgram(s) per liter

ug/m^3 = microgram(s) per cubic meter

L/m^3 = liters per cubic meter

LNAPL = light non-aqueous phase liquid

N = no

N/A = not available; insufficient data

PAH = polycyclic aromatic hydrocarbon

RRO = Residual range organics

SD = standard deviation

SVOCs = semi-volatile organic compounds

TEQ = toxicity equivalents

UCL = upper confidence limit on the mean

VF = volatilization factor

VOC = volatile organic compound

Y = yes

Table 3-6
Area-Wide Summary Statistics and Maximum Exposure Point Concentrations for Offsite Groundwater in All Wells (2009 through 2011)

Human Health Risk Assessment - PPRTV Scenario and ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	Sample Size [b]	Number of Detects [b]	FOD (%)	Min [b]	Max [b]	Mean [b]	Median [b]	SD [b]	COPC? [c] (Y/N)	Groundwater EPC [a] (ug/L)
Miscellaneous										
Sulfolane	700	367	52	3.48	443	56.1	21.6	68.7	Y	4.4E+02

Notes:

[a] The maximum detected concentration was used to represent the EPC.

All concentrations are in units of ug/L, unless noted otherwise.

[b] Statistics were calculated using the most recent two years of groundwater data (2009 through 2011) for offsite wells without LNAPL.

[c] COPCs are defined as described in the main text and Table 3-2a.

COPC = constituent of potential concern

EPC = exposure point concentration

FOD = frequency of detection

ug/L = microgram(s) per liter

LNAPL = light non-aqueous phase liquid

N = no

SD = standard deviation

Y = yes

Table 3-7
Area-Wide Summary Statistics and UCL Exposure Point Concentrations for Offsite Groundwater in Exposure Unit 1 (2009 through 2011)

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	Sample Size [b]	Number of Detects [b]	FOD (%)	Min [b]	Max [b]	Mean [b]	Median [b]	SD [b]	UCL Method	UCL [b]	COPC? [c] (Y/N)	Groundwater EPC [a] (ug/L)
Miscellaneous												
Sulfolane	105	104	99	15.8	443	139	122	72.8	95% Chebyshev (Mean, Sd) UCL	170	Y	1.7E+02

Notes:
[a] The EPC is defined as the 95% UCL calculated using ProUCL v. 4.00.05.
All concentrations are in units of ug/L, unless noted otherwise.
[b] Statistics were calculated using the most recent two years of groundwater data (2009 through 2011) for offsite wells in Exposure Unit 1 without LNAPL.
[c] COPCs are defined as described in the main text and Table 3-2a.
COPC = constituent of potential concern
EPC = exposure point concentration
FOD = frequency of detection
Groundwater wells in Exposure Unit 1 were defined by a boundary that includes all wells with maximum concentrations greater than 100 ug/L.
ug/L = microgram(s) per liter
LNAPL = light non-aqueous phase liquid
N = no
SD = standard deviation
UCL = upper confidence limit on the mean
Y = yes

Table 3-8a
Area-Wide Summary Statistics and Maximum Exposure Point Concentrations for Offsite Groundwater in Exposure Unit 2 (2009 through 2011)

Human Health Risk Assessment - PPRTV Scenario and ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	Sample Size [b]	Number of Detects [b]	FOD (%)	Min [b]	Max [b]	Mean [b]	Median [b]	SD [b]	COPC? [c] (Y/N)	Groundwater EPC [a] (ug/L)
Miscellaneous										
Sulfolane	73	72	99	8.63	144	53.3	46.9	7.51	Y	1.4E+02

Notes:
[a] The maximum detected concentration was used to represent the EPC.
All concentrations are in units of ug/L, unless noted otherwise.
[b] Statistics were calculated using the most recent two years of groundwater data (2009 through 2011) for offsite wells in Exposure Unit 2 without LNAPL.
[c] COPCs are defined as described in the main text and Table 3-2a.
COPC = constituent of potential concern
EPC = exposure point concentration
FOD = frequency of detection
Groundwater wells in Exposure Unit 2 were defined by a boundary that includes all wells with maximum concentrations greater than 25 ug/L but less than than 100 ug/L.
ug/L = microgram(s) per liter
LNAPL = light non-aqueous phase liquid
N = no
SD = standard deviation
UCL = upper confidence limit on the mean
Y = yes

Table 3-8b
Area-Wide Summary Statistics and UCL Exposure Point Concentrations for Offsite Groundwater in Exposure Unit 2 (2009 through 2011)

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	Sample Size [b]	Number of Detects [b]	FOD (%)	Min [b]	Max [b]	Mean [b]	Median [b]	SD [b]	UCL Method	UCL [b]	COPC? [c] (Y/N)	Groundwater EPC [a] (ug/L)
Miscellaneous												
Sulfolane	73	72	99	8.63	144	53.3	46.9	29.8	95% Approximate Gamma UCL	59.1	Y	5.9E+01

Notes:
[a] The EPC is defined as the 95% UCL calculated using ProUCL v. 4.00.05.
All concentrations are in units of ug/L, unless noted otherwise.
[b] Statistics were calculated using the most recent two years of groundwater data (2009 through 2011) for offsite wells in Exposure Unit 2 without LNAPL.
[c] COPCs are defined as described in the main text and Table 3-2a.
COPC = constituent of potential concern
EPC = exposure point concentration
FOD = frequency of detection
Groundwater wells in Exposure Unit 2 were defined by a boundary that includes all wells with maximum concentrations greater than 25 ug/L but less than 100 ug/L.
ug/L = microgram(s) per liter
LNAPL = light non-aqueous phase liquid
N = no
SD = standard deviation
UCL = upper confidence limit on the mean
Y = yes

Table 3-9a
Area-Wide Summary Statistics and Maximum Exposure Point Concentrations for Offsite Groundwater in Exposure Unit 3 (2009 through 2011)

Human Health Risk Assessment - PPRTV Scenario and ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	Sample Size [b]	Number of Detects [b]	FOD (%)	Min [b]	Max [b]	Mean [b]	Median [b]	SD [b]	COPC? [c] (Y/N)	Groundwater EPC [a] (ug/L)
Miscellaneous										
Sulfolane	294	177	60	3.48	80.2	10.9	9.04	7.51	Y	8.0E+01

Notes:
[a] The maximum detected concentration was used to represent the EPC.
All concentrations are in units of ug/L, unless noted otherwise.
[b] Statistics were calculated using the most recent two years of groundwater data (2009 through 2011) for offsite wells in Exposure Unit 3 without LNAPL.
[c] COPCs are defined as described in the main text and Table 3-2a.
COPC = constituent of potential concern
EPC = exposure point concentration
FOD = frequency of detection
Groundwater wells in Exposure Unit 3 were defined by a boundary that includes all wells with maximum concentrations greater than the detection limit but less than than 25 ug/L.
ug/L = microgram(s) per liter
LNAPL = light non-aqueous phase liquid
N = no
SD = standard deviation
UCL = upper confidence limit on the mean
Y = yes

Table 3-9b
Area-Wide Summary Statistics and UCL Exposure Point Concentrations for Offsite Groundwater in Exposure Unit 3 (2009 through 2011)

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	Sample Size [b]	Number of Detects [b]	FOD (%)	Min [b]	Max [b]	Mean [b]	Median [b]	SD [b]	UCL Method	UCL [b]	COPC? [c] (Y/N)	Groundwater EPC [a] (ug/L)
Miscellaneous												
Sulfolane	294	177	60	3.48	80.2	10.9	9.04	7.51	95% Chebyshev (Mean, Sd) UCL	10.2	Y	1.0E+01

Notes:
[a] The EPC is defined as the 95% UCL calculated using ProUCL v. 4.00.05.
All concentrations are in units of ug/L, unless noted otherwise.
[b] Statistics were calculated using the most recent two years of groundwater data (2009 through 2011) for offsite wells in Exposure Unit 3 without LNAPL.
[c] COPCs are defined as described in the main text and Table 3-2a.
COPC = constituent of potential concern
EPC = exposure point concentration
FOD = frequency of detection
Groundwater wells in Exposure Unit 3 were defined by a boundary that includes all wells with maximum concentrations greater than the detection limit but less than than 25 ug/L.
ug/L = microgram(s) per liter
LNAPL = light non-aqueous phase liquid
N = no
SD = standard deviation
UCL = upper confidence limit on the mean
Y = yes

Table 3-10
Area-Wide Summary Statistics and Maximum Exposure Point Concentrations for Offsite Surface Water (Estimated from Porewater Surrogate Data)

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	Sample Size [b]	Number of Detects [b]	FOD (%)	Min [b]	Max [b]	Mean [b]	Median [b]	SD [b]	COPC? [c] (Y/N)	Surface Water EPC [a] (ug/L)
Miscellaneous										
Sulfolane	3	2	67	28.7	156	92.35	92.35	90.01	Y	1.6E+02

Notes:

[a] The maximum detected concentration was used to represent the EPC.

All concentrations are in units of ug/L, unless noted otherwise.

[b] Statistics were calculated using porewater data collected in 2012.

[c] COPCs are defined as described in the main text and Table 3-2a.

COPC = constituent of potential concern

EPC = exposure point concentration

FOD = frequency of detection

ug/L = microgram(s) per liter

N = no

SD = standard deviation

Y = yes

Table 3-11
Chemical Specific Information and Soil Volatilization Factors for Human Health Risk Assessment

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Constituents	Volatile? [a]	Molecular Weight (g/mol)	Henry's Law Constant (atm-m^3/mol)	Henry's Law Constant (unitless)	Solubility in Water (mg/L-water)	Diffusivity in Air (cm^2/sec)	Diffusivity in Water (cm^2/sec)	Koc (cm^3/g)	Kd [b] (cm^3/g)	Apparent Diffusivity [c] Calculated (cm^2/sec)	Soil to Air Volatilization Factor: Calculated [a] (m^3/kg)	Soil to Air Volatilization Factor: Published (m^3/kg)	Soil to Air Volatilization Factor: Selected Value (m^3/kg)	Soil Saturation Limit: Calculated (mg/kg)	Soil Saturation Limit: Published (mg/kg)	Soil Saturation Limit: Selected Value (mg/kg)
Metals																
Antimony	N	1.22E+02 RSL	--	--	--	--	--	7.50E+03 RSL	4.50E+01 RSL	--	--	--	--	--	--	--
Arsenic	N	7.49E+01 RSL	--	--	--	--	--	4.83E+03 RSL	2.90E+01 RSL	--	--	--	--	--	--	--
Barium	N	1.37E+02 RSL	--	--	--	--	--	6.67E+02 RSL	4.00E+00 RSL	--	--	--	--	--	--	--
Cadmium	N	1.12E+02 RSL	--	--	--	--	--	1.25E+04 RSL	7.50E+01 RSL	--	--	--	--	--	--	--
Chromium, Total	N	5.20E+01 RSL	--	--	--	--	--	3.00E+08 RSL	1.80E+06 RSL	--	--	--	--	--	--	--
Copper	N	6.36E+01 RSL	--	--	--	--	--	5.83E+03 RSL	3.50E+01 RSL	--	--	--	--	--	--	--
Lead	N	2.07E+02 RSL	--	--	--	--	--	1.50E+05 RSL	9.00E+02 RSL	--	--	--	--	--	--	--
Nickel	N	5.87E+01 RSL	--	--	--	--	--	1.08E+04 RSL	6.50E+01 RSL	--	--	--	--	--	--	--
Selenium	N	7.90E+01 RSL	--	--	--	--	--	8.33E+02 RSL	5.00E+00 RSL	--	--	--	--	--	--	--
Silver	N	1.08E+02 RSL	--	--	--	--	--	1.38E+03 RSL	8.30E+00 RSL	--	--	--	--	--	--	--
Zinc	N	6.54E+01 RSL	--	--	--	--	--	1.03E+04 RSL	6.20E+01 RSL	--	--	--	--	--	--	--
VOCs																
1,2,4-Trimethylbenzene	Y	1.20E+02 RSL	6.16E-03 RSL	2.52E-01 RSL	5.70E+01 RSL	6.07E-02 RSL	7.92E-06 RSL	6.14E+02 RSL	3.69E+00 RSL	2.06E-04 RSL	8.72E+03	8.52E+03 RSL	8.52E+03 RSL	2.18E+02	2.19E+02 RSL	2.19E+02 RSL
1,3,5-Trimethylbenzene	Y	1.20E+02 RSL	8.77E-03 RSL	3.59E-01 RSL	4.82E+01 RSL	6.02E-02 RSL	7.84E-06 RSL	6.02E+02 RSL	3.61E+00 RSL	2.96E-04 RSL	7.28E+03	7.12E+03 RSL	7.12E+03 RSL	1.82E+02	1.82E+02 RSL	1.82E+02 RSL
4-Isopropyltoluene (p-cymene)	Y	1.34E+02 AIS	1.10E-02 IS	4.51E-01 AIS	2.34E+01 AIS	5.27E-02 AIS	7.32E-06 AIS	1.12E+03 AIS	6.72E+00 AIS	1.78E-04 AIS	9.38E+03	--	9.38E+03 calc	1.62E+02	--	1.62E+02 calc
Benzene	Y	7.81E+01 RSL	5.55E-03 RSL	2.27E-01 RSL	1.79E+03 RSL	8.95E-02 RSL	1.03E-05 RSL	1.46E+02 RSL	8.75E-01 RSL	1.03E-03 RSL	3.90E+03	3.81E+03 RSL	3.81E+03 RSL	1.82E+03	1.82E+03 RSL	1.82E+03 RSL
Ethylbenzene	Y	1.06E+02 RSL	7.88E-03 RSL	3.22E-01 RSL	1.69E+02 RSL	6.85E-02 RSL	8.46E-06 RSL	4.46E+02 RSL	2.68E+00 RSL	4.03E-04 RSL	6.24E+03	6.10E+03 RSL	6.10E+03 RSL	4.79E+02	4.80E+02 RSL	4.80E+02 RSL
Isopropylbenzene (cumene)	Y	1.20E+02 RSL	1.15E-02 RSL	4.70E-01 RSL	6.13E+01 RSL	6.03E-02 RSL	7.86E-06 RSL	6.98E+02 RSL	4.19E+00 RSL	3.36E-04 RSL	6.84E+03	6.68E+03 RSL	6.68E+03 RSL	2.68E+02	2.68E+02 RSL	2.68E+02 RSL
Methyl tert-butyl ether	Y	8.82E+01 RSL	5.87E-04 RSL	2.40E-02 RSL	5.10E+04 RSL	7.53E-02 RSL	8.59E-06 RSL	1.16E+01 RSL	6.94E-02 RSL	5.38E-04 RSL	5.40E+03	5.28E+03 RSL	5.28E+03 RSL	8.87E+03	8.87E+03 RSL	8.87E+03 RSL
Methylene chloride	Y	8.49E+01 RSL	3.25E-03 RSL	1.33E-01 RSL	1.30E+04 RSL	9.99E-02 RSL	1.25E-05 RSL	2.17E+01 RSL	1.30E-01 RSL	2.69E-03 RSL	2.41E+03	2.36E+03 RSL	2.36E+03 RSL	3.32E+03	3.32E+03 RSL	3.32E+03 RSL
n-Butylbenzene	Y	1.34E+02 AIS	1.59E-02 IS	6.50E-01 AIS	1.18E+01 AIS	5.28E-02 AIS	7.33E-06 AIS	1.48E+03 AIS	8.89E+00 AIS	1.95E-04 AIS	8.97E+03	8.77E+03 RSL	8.77E+03 RSL	1.08E+02	1.08E+02 RSL	1.08E+02 RSL
n-Propylbenzene	Y	1.20E+02 RSL	1.05E-02 RSL	4.29E-01 RSL	5.22E+01 RSL	6.02E-02 RSL	7.83E-06 RSL	8.13E+02 RSL	4.88E+00 RSL	2.64E-04 RSL	7.71E+03	7.53E+03 RSL	7.53E+03 RSL	2.64E+02	2.64E+02 RSL	2.64E+02 RSL
sec-Butylbenzene	Y	1.34E+02 AIS	1.76E-02 IS	7.22E-01 AIS	1.76E+01 AIS	5.28E-02 AIS	7.33E-06 AIS	1.33E+03 AIS	7.98E+00 AIS	2.40E-04 AIS	8.08E+03	--	8.08E+03 calc	1.45E+02	--	1.45E+02 calc
tert-Butylbenzene	Y	1.34E+02 AIS	1.32E-02 IS	5.41E-01 AIS	2.95E+01 AIS	5.30E-02 AIS	7.37E-06 AIS	1.00E+03 AIS	6.00E+00 AIS	2.40E-04 AIS	8.09E+03	--	8.09E+03 calc	1.83E+02	--	1.83E+02 calc
Toluene	Y	9.21E+01 RSL	6.64E-03 RSL	2.71E-01 RSL	5.26E+02 RSL	7.78E-02 RSL	9.20E-06 RSL	2.34E+02 RSL	1.40E+00 RSL	7.04E-04 RSL	4.72E+03	4.61E+03 RSL	4.61E+03 RSL	8.17E+02	8.18E+02 RSL	8.18E+02 RSL
Trichlorofluoromethane (Freon 11)	Y	1.37E+02 RSL	9.70E-02 RSL	3.97E+00 RSL	1.10E+03 RSL	6.54E-02 RSL	1.00E-05 RSL	4.39E+01 RSL	2.63E-01 RSL	1.22E-02 RSL	1.14E+03	1.11E+03 RSL	1.11E+03 RSL	1.21E+03	1.23E+03 RSL	1.23E+03 RSL
Xylenes	Y	1.06E+02 RSL	5.18E-03 RSL	2.12E-01 RSL	1.06E+02 RSL	8.47E-02 RSL	9.90E-06 RSL	3.83E+02 RSL	2.30E+00 RSL	3.81E-04 RSL	6.42E+03	6.27E+03 RSL	6.27E+03 RSL	2.58E+02	2.58E+02 RSL	2.58E+02 RSL
SVOCs																
2-Methylnaphthalene	Y	1.42E+02 RSL	5.18E-04 RSL	2.12E-02 RSL	2.46E+01 RSL	5.24E-02 RSL	7.78E-06 RSL	2.48E+03 RSL	1.49E+01 RSL	3.84E-06 RSL	6.39E+04	6.24E+04 RSL	6.24E+04 RSL	3.68E+02	3.68E+02 RSL	3.68E+02 RSL
Dibenzofuran	Y	1.68E+02 RSL	2.13E-04 RSL	8.71E-03 RSL	3.10E+00 RSL	4.10E-02 RSL	7.38E-06 RSL	9.16E+03 RSL	5.50E+01 RSL	3.37E-07 RSL	2.16E+05	2.11E+05 RSL	2.11E+05 RSL	1.71E+02	1.71E+02 RSL	1.71E+02 RSL
PAHs																
Benzo (a) anthracene	N	2.28E+02 RSL	1.20E-05 RSL	4.91E-04 RSL	9.40E-03 RSL	5.09E-02 RSL	5.94E-06 RSL	1.77E+05 RSL	1.06E+03 RSL	1.25E-09 RSL	3.54E+06	--	3.54E+06 calc	9.98E+00	--	9.98E+00 calc
Benzo (a) pyrene	N	2.52E+02 RSL	4.57E-07 RSL	1.87E-05 RSL	1.62E-03 RSL	4.76E-02 RSL	5.56E-06 RSL	5.87E+05 RSL	3.52E+03 RSL	2.33E-11 RSL	2.60E+07	--	2.60E+07 calc	5.71E+00	--	5.71E+00 calc
Benzo (b) fluoranthene	N	2.52E+02 RSL	6.57E-07 RSL	2.69E-05 RSL	1.50E-03 RSL	4.76E-02 RSL	5.56E-06 RSL	5.99E+05 RSL	3.60E+03 RSL	2.84E-11 RSL	2.35E+07	--	2.35E+07 calc	5.39E+00	--	5.39E+00 calc
Benzo (g,h,i) perylene	N	2.76E+02 SRC & RAIS	3.31E-07 RAIS	1.36E-05 RAIS	2.60E-04 RAIS	--	--	--	--	--	--	--	--	--	--	--
Benzo (k) fluoranthene	N	2.52E+02 RSL	5.84E-07 RSL	2.39E-05 RSL	8.00E-04 RSL	4.76E-02 RSL	5.56E-06 RSL	5.87E+05 RSL	3.52E+03 RSL	2.69E-11 RSL	2.42E+07	--	2.42E+07 calc	2.82E+00	--	2.82E+00 calc
Chrysene	N	2.28E+02 RSL	5.23E-06 RSL	2.14E-04 RSL	2.00E-03 RSL	2.61E-02 RSL	6.75E-06 RSL	1.81E+05 RSL	1.08E+03 RSL	3.07E-10 RSL	7.15E+06	--	7.15E+06 calc	2.17E+00	--	2.17E+00 calc
Dibenzo (a,h) anthracene	N	2.78E+02 RSL	1.41E-07 RSL	5.76E-06 RSL	2.49E-03 RSL	4.46E-02 RSL	5.21E-06 RSL	1.91E+06 RSL	1.15E+04 RSL	4.09E-12 RSL	6.19E+07	--	6.19E+07 calc	2.86E+01	--	2.86E+01 calc
Fluoranthene	N	2.02E+02 RSL	8.86E-06 RSL	3.62E-04 RSL	2.60E-01 RSL	2.76E-02 RSL	7.18E-06 RSL	5.55E+04 RSL	3.33E+02 RSL	1.69E-09 RSL	3.04E+06	--	3.04E+06 calc	8.65E+01	--	8.65E+01 calc
Fluorene	Y	1.66E+02 RSL	9.62E-05 RSL	3.93E-03 RSL	1.69E+00 RSL	4.40E-02 RSL	7.89E-06 RSL	9.16E+03 RSL	5.50E+01 RSL	1.64E-07 RSL	3.10E+05	3.03E+05 RSL	3.03E+05 RSL	9.31E+01	--	9.31E+01 calc
Indeno (1,2,3-cd) pyrene	N	2.76E+02 RSL	3.48E-07 RSL	1.42E-05 RSL	1.90E-04 RSL	4.48E-02 RSL	5.23E-06 RSL	1.95E+06 RSL	1.17E+04 RSL	5.70E-12 RSL	5.25E+07	--	5.25E+07 calc	2.22E+00	--	2.22E+00 calc
Naphthalene	Y	1.28E+02 RSL	4.40E-04 RSL	1.80E-02 RSL	3.10E+01 RSL	6.05E-02 RSL	8.38E-06 RSL	1.54E+03 RSL	9.26E+00 RSL	6.02E-06 RSL	5.11E+04	4.99E+04 RSL	4.99E+04 RSL	2.90E+02	--	2.90E+02 calc
Phenanthrene	Y	1.78E+02 SRC & RAIS	4.23E-05 RAIS	1.73E-03 RAIS	1.15E+00 RAIS	3.45E-02 RAIS	6.69E-06 RAIS	1.67E+04 RAIS	1.00E+02 RAIS	3.13E-08 RAIS	7.08E+05	--	7.08E+05 calc	1.15E+02	--	1.15E+02 calc
Pyrene	N	2.02E+02 RSL	1.19E-05 RSL	4.87E-04 RSL	1.35E-01 RSL	2.78E-02 RSL	7.25E-06 RSL	5.43E+04 RSL	3.26E+02 RSL	2.29E-09 RSL	2.62E+06	2.56E+06 RSL	2.56E+06 RSL	4.40E+01	--	4.40E+01 calc
Total Benzo(a)pyrene TEQ	N	2.52E+02 RSL	4.57E-07 RSL	1.87E-05 RSL	1.62E-03 RSL	4.76E-02 RSL	5.56E-06 RSL	5.87E+05 RSL	3.52E+03 RSL	2.33E-11 RSL	2.60E+07	--	2.60E+07 calc	5.71E+00	--	5.71E+00 calc
Miscellaneous																
Cyanide	Y	2.70E+01 RSL	1.33E-04 RSL	5.44E-03 RSL	1.00E+06 RSL	2.11E-01 RSL	2.46E-05 RSL	--	--	--	--	5.01E+04 RSL	5.01E+04 RSL	--	1.00E+07 RSL	1.00E+07 RSL
Sulfolane	N	1.20E+02 EPI	1.42E-09 EPI	5.82E-08 EPI	4.56E+05 EPI	--	--	--	--	--	--	--	--	--	--	--
GRO	NA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
DRO	NA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
RRO	NA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 3-11
Chemical Specific Information and Soil Volatilization Factors for Human Health Risk Assessment

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Notes:
a = Volatilization factors were calculated as described in USEPA (2011d) for chemicals with molecular weight < 200 g/mol and Henry's Law Constant >1x10^{-5} (USEPA, 2004).
atm-m^3/mol = atmospheres × cubic meters per mole
b = Kd values calculated by multiplying Koc by the default fraction organic carbon (0.006) from USEPA (2011d) unless provided by USEPA (1996).
c = Apparent diffisivity calculated based on equation provided by Section 4.10.2 of USEPA guidance (2011d).
cm^2/sec = square centimeter(s) per second
cm^3/g = cubic centimeter(s) per gram
d = Values presented in USEPA (2011d).
e = naphthalene surrogate used
EPI = EpiSuite software v. 4.0
g/mol = gram(s) per mole
Kd = soil-water distribution coefficient (inorganic compounds)
Koc = organic carbon partition coefficient (organics)
m^3/kg = cubic meter(s) per kilogram
mg/L = milligram(s) per liter
mm Hg = millimeter(s) of mercury
PAH = polycyclic aromatic hydrocarbon
RAIS = parameter selected from ORNL (2010)
RSL = parameter selected from USEPA (2011d)
SRC = parameter selected from SRC (2010)
USEPA = U.S. Environmental Protection Agency
VOC = volatile organic compound
-- = not applicable

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Table 3-12
Human Health Exposure Parameters - PPRTV Scenario and ARCADIS Comparative Scenario

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	Symbol	Units	Onsite and Offsite Commercial/Industrial Indoor Worker		Onsite Commercial/Industrial Outdoor Worker		Onsite and Offsite Construction/Trench Worker		Onsite Adult Visitor		Offsite Adult Resident		Offsite Child (1-6 yr) Resident		Offsite Infant (0-1 yr) Resident		Offsite Adult Recreator		Offsite Child (1-6 yr) Recreator	
			CI		CIo		CST		VIS		ADUR		CHR		INF		AREC		CREC	
General Factors																				
Averaging Time (cancer)	ATc	days	25,550	a,b	25,550	a,b	25,550	a	25,550	a	25,550	a,b	25,550	a,b	25,550	a,b	25,550	a,b	25,550	a,b
Averaging Time (noncancer)	ATnc	days	9,125	a	9,125	a	365	a	10,950	a	10,950	a	2,190	a	365	a	10,950	a	2,190	a
Body Weight	BW	kg	70	b, d	70	b, d	70	d, f	70	b	70	b, d	15	b,d	6.75	n	70	b, d	15	o
Exposure Frequency - Soil	EF	days/year	250	b, c	250	b, c	125	d, f	12	PJ	270	b, c	270	b, c	270	b,d	–		–	
Exposure Frequency - Groundwater	EFgw	days/year	250	b, c	250	b, c	125	d, f	12	PJ	350	b	350	b	350	b,d	–		–	
Exposure Frequency - Surface water	EFsw	days/year	–		–		–		–		60	cons	60	cons	–		60	cons	60	cons
Exposure Duration	ED	years	25	b	25	b	1	PJ	30	b	30	b	6	b	1	n	30	b	6	b
Exposure Time	ET	hr/day	8	PJ	8	PJ	1	PJ	2	PJ	12	PJ	12	PJ	12	PJ	1	cons	1	cons
Groundwater - Ingestion (Oral)																				
Groundwater Ingestion Rate (drinking water)	IRgw	L/day	2	b	2	b	–		–		2	b	1	d	1.05	l	–		–	
Groundwater Ingestion Rate (incidental)	IRinc_gw	L/day	–		–		0.0037	m	–		–		–		–		–		–	
Fraction Ingested from Source	Figw	unitless	1	cons	1	cons	1	cons	–		1	cons	1	cons	1	cons	–		–	
Groundwater - Dermal Contact																				
Exposed Skin Surface Area	SSAgw	cm^2	–		–		2,230	k	–		–		–		–		–		–	
Event Frequency	EvFgw	events/day	–		–		1	--	–		–		–		–		–		–	
Event Time	EvTgw	hr/event	–		–		1	PJ	–		–		–		–		–		–	
Groundwater - Inhalation of Volatiles																				
Exposure Frequency - Trench Air	EFtr	days/year	–		–		125	PJ	–		–		–		–		–		–	
Soil - Ingestion (Oral)																				
Incidental Soil Ingestion Rate	IRs	mg/day	–		100	b, f	330	i	–		–		–		–		–		–	
Fraction Ingested from Source	FI	unitless	–		1	--	1	cons	–		–		–		–		–		–	
Soil - Dermal Contact																				
Exposed Skin Surface Area	SA	cm^2	–		2,230	k	2,230	k	–		–		–		–		–		–	
Skin Adherence Factor	AF	mg/cm^2-day	–		0.2	b, h	0.3	i	–		–		–		–		–		–	
Fraction in Contact with Soil	FC	unitless	–		1	b	1	b	–		–		–		–		–		–	
Event Frequency	EvFs	events/day	–		1	--	1	--	–		–		–		–		–		–	
Soil - Inhalation of Dust and Vapor																				
Age-Adjusted Intake Factor, Inhalation	IFi	m^3-yr/kg-day	–		–				–		–		–		–		–		–	
Particulate Emission Factor	PEF	m^3/kg	–		1.32E+09	b,e	1.00E+06	e,j	–		1.32E+09	b,e	1.32E+09	e	1.32E+09	e	–		–	
Homegrown Produce Ingestion																				
Fruit Ingestion Rate	IRPfr	mg/day	–		–		–		–		259,000	g	223,500	g	155,250	g	–		–	
Vegetable Ingestion Rate	IRPvg	mg/day	–		–		–		–		413,000	g	201,000	g	109,350	g	–		–	
Fraction Ingested from Source	Flp	unitless	–		–		–		–		0.25	PJ	0.25	PJ	0.25	PJ	–		–	
Bioconcentration Factor	BCF	L/kg ww	–		–		–		–		1	cons	1	cons	1	cons				
Surface water - Ingestion (Oral)																				
Surface water Ingestion Rate (incidental)	IRinc_sw	L/hour	–		–		–		–		0.071	p	0.12	p	–		0.071	p	0.12	p
Fraction Ingested from Source	Fisw	unitless	–		–		–		–		1	cons	1	cons	–		1	cons	1	cons

Table 3-12
Human Health Exposure Parameters - PPRTV Scenario and ARCADIS Comparative Scenario

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Notes:
a. The averaging period for cancer risk is the expected lifespan of 70 years expressed in days (70 years * 365 days/year). The averaging period for non-cancer risk is the total exposure period expressed in days (ED * 365 days/year).
b. ADEC (2010). Risk Assessment Procedures Manual. July.
c. Soil exposure frequency is based on the climate zone in which the site is located, consistent with ADEC's Cleanup Level Guidance (DEC 2008). Residential and recreation/subsistence user soil exposure frequency is 270 d/yr for the under 40-inch zone. For commercial/industrial workers the soil exposure frequency is 250 d/yr for the
d. USEPA. 1989. Risk Assessment Guidance for Superfund.Volume I, Human Health Evaluation Manual (Part A) . EPA/540/1-89-002. December.
e. CALEPA. 2011. Human Health RIsk Assessment Note 1. Recommended DTSC Default Exposure Factors for Use in Risk Assessment at California Hazardous Waste Sites and Permitted Facilities. May.
f. USEPA. 1991. Standard Default Exposure Factors, Interim Final . OSWER Directive: 9285.6-03. March.
g. USEPA (2011). Exposure Factors Handbook. For fruit: Table 9-3, 95th percentile per capita intake (value for ages 3-5 years used for child). For vegetables: Table 9-3, 95th percentile per capita intake of all vegetables (value for ages 3-5 years used for child). IRPs in EFH were multiplied by body weight.
h. USEPA (2004). Risk Assessment Guidance for Superfund, Vol 1, Part E, Supplemental Guidance for Dermal Risk Assessment. Office of Emergency and Remedial
i. USEPA (2002a). Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. OSWER 9355.4-24. December.
j. This PEF value corresponds to a respirable dust concentration of 1 mg/m3. This is based on a maximum concentration of dust in air of 10 mg/m3 recommended by the American Conference of Governmental Industrial Hygienists (ACGIH 2004, Threshold Limit Values and Biological Exposure Indices), and the assumption that 10 percent of the mass of particles are in the respirable PM10 range.
k. USEPA (2011). Exposure Factors Handbook. Table 7-2, average of adult male and adult female mean values for head and hands.
l. USEPA (2011). Exposure Factors Handbook. Table 3-1, time-weighted 95th percentile ingestion rate for infants.
m. USEPA (2011). Exposure Factors Handbook. Table 3-93, mean incidental ingestion of water during wading/spashing activities.
n. USEPA. 2008. Child-Specific Exposure Factors Handbook. EPA/600/R-06/096F. September.
o. See footnotes b and d.
p. USEPA (2011). Exposure Factors Handbook. Recommended upper percentile values for swimmers from Table 3-5: maximum for adults, 97th percentile for children age 18 and under.

Exposure equations are presented in Section 3 of the main text.
Exposure parameters with alternate values in the PPRTV and ARCADIS Scenarios are highlighted in gray.

cm	Centimeter.
cons	Conservative assumption (see text).
hr	Hour.
kg	Kilogram.
L	liter
m	Meter.
mg	milligrams
PJ	Professional judgement
ww	wet weight
yr	year

Table 3-13
Human Health Toxicity Values

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Constituents		CSFo (mg/kg-day)$^{-1}$		CSFd (mg/kg-day)$^{-1}$		IUR (µg/m^3)$^{-1}$		Chronic RfDo mg/kg-day		Chronic RfDd mg/kg-day		Chronic RfC mg/m^3		Subchronic RfDo mg/kg-day		Subchronic RfDd mg/kg-day		Subchronic RfC mg/m^3		ABSo unitless	ABSd unitless
Metals																					
Antimony		NC	-	NC	-	NC	-	4.0E-04	I	6.0E-05	Calc	NA	-	4.0E-04	PROV	6.0E-05	Calc	NA	Chronic	0.15	0.00
Arsenic		1.5E+00	I	1.5E+00	Calc	4.3E-03	I	3.0E-04	I	3.0E-04	Calc	1.5E-05	C	5.0E-03	PROV	5.0E-03	Calc	1.5E-05	Chronic	1	0.03
Barium		NC	-	NC	-	NC	-	2.0E-01	I	1.4E-02	Calc	5.0E-04	H	7.0E-02	HEAST	4.9E-03	Calc	5.0E-03	HEAST	0.07	0.00
Cadmium	a	NC	-	NC	-	1.8E-03	I	1.0E-03	I	2.5E-05	Calc	2.0E-05	C	1.0E-03	Chronic	2.5E-05	Calc	9.0E-04	PROV	0.025	0.001
Chromium, Total	b	NC	-	NC	-	NC	-	1.5E+00	I	2.0E-02	Calc	NA	-	1.5E+00	HEAST	2.0E-02	Calc	NA	Chronic	0.013	0.00
Copper		NC	-	NC	-	NC	-	4.0E-02	H	4.0E-02	Calc	NA	-	4.0E-02	HEAST	4.0E-02	Calc	NA	Chronic	1	0.00
Iron		NC	-	NC	-	NC	-	7.0E-01	P	7.0E-01	Calc	NA	-	7.0E-01	PROV	7.0E-01	Calc	NA	Chronic	1	0.00
Lead	c	NE	-	NE	-	NE	-	NE	-	NE	-	NE	-	NE	-	NE	-	NE	-	1	0.00
Nickel		NC	-	NC	-	2.6E-04	C	2.0E-02	I	8.0E-04	Calc	9.0E-05	A	2.0E-02	HEAST	8.0E-04	Calc	9.0E-05	Chronic	0.04	0.00
Selenium		NC	-	NC	-	NC	-	5.0E-03	I	5.0E-03	Calc	2.0E-02	C	5.0E-03	HEAST	5.0E-03	Calc	2.0E-02	Chronic	1	0.00
Silver		NC	-	NC	-	NC	-	5.0E-03	I	2.0E-04	Calc	NA	-	5.0E-03	HEAST	2.0E-04	Calc	NA	Chronic	0.04	0.00
Zinc		NC	-	NC	-	NC	-	3.0E-01	I	3.0E-01	Calc	NA	-	3.0E-01	HEAST	3.0E-01	Calc	NA	Chronic	1	0.00
VOCs																					
1,2,4-Trimethylbenzene		NC	-	NC	-	NC	-	NA	-	NA	Calc	7.0E-03	P	NA	Chronic	NA	Calc	7.0E-02	PROV	1	0.00
1,3,5-Trimethylbenzene		NC	-	NC	-	NC	-	1.0E-02	X	1.0E-02	Calc	NA	-	1.0E-01	PROV	1.0E-01	Calc	1.0E-02	PROV	1	0.00
4-Isopropyltoluene (p-cymene)		NC	-	NC	-	NC	-	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.00
Benzene		5.5E-02	I	5.5E-02	Calc	7.8E-06	I	4.0E-03	I	4.0E-03	Calc	3.0E-02	I	1.0E-02	PROV	1.0E-02	Calc	8.0E-02	PROV	1	0.00
Cyclohexane		NC	-	NC	-	NC	-	NA	-	NA	Calc	6.0E+00	I	NA	Chronic	NA	Calc	6.0E+00	Chronic	1	0.00
Ethylbenzene		1.1E-02	C	1.1E-02	Calc	2.5E-06	C	1.0E-01	I	1.0E-01	Calc	1.0E+00	I	5.0E-02	PROV	5.0E-02	Calc	9.0E+00	PROV	1	0.00
Isopropylbenzene (cumene)		NC	-	NC	-	NC	-	1.0E-01	I	1.0E-01	Calc	4.0E-01	I	4.0E-01	HEAST	4.0E-01	Calc	9.0E-02	HEAST	1	0.00
Methyl tert-butyl ether		1.8E-03	C	1.8E-03	Calc	2.6E-07	C	NA	-	NA	Calc	3.0E+00	I	NA	Chronic	NA	Calc	3.0E+00	Chronic	1	0.00
Methylene chloride		7.5E-03	I	7.5E-03	Calc	4.7E-07	I	6.0E-02	I	6.0E-02	Calc	1.0E+00	A	6.0E-02	HEAST	6.0E-02	Calc	3.0E+00	HEAST	1	0.00
n-Butylbenzene		NC	-	NC	-	NC	-	5.0E-02	P	5.0E-02	Calc	NA	-	1.0E-01	PPRTV	1.0E-01	Calc	NA	Chronic	1	0.00
n-Hexane		NC	-	NC	-	NC	-	6.0E-02	H	6.0E-02	Calc	7.0E-01	I	3.0E-01	PROV	3.0E-01	Calc	2.0E+00	PROV	1	0.00
n-Propylbenzene		NC	-	NC	-	NC	-	1.0E-01	X	1.0E-01	Calc	1.0E+00	X	1.0E-01	PROV	1.0E-01	Calc	1.0E+00	PROV	1	0.10
sec-Butylbenzene		NC	-	NC	-	NC	-	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.00
tert-Butylbenzene		NC	-	NC	-	NC	-	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.00
Toluene		NC	-	NC	-	NC	-	8.0E-02	I	8.0E-02	Calc	5.0E+00	I	8.0E-01	PROV	8.0E-01	Calc	5.0E+00	PROV	1	0.00
Trichlorofluoromethane (Freon 11)		NC	-	NC	-	NC	-	3.0E-01	I	3.0E-01	Calc	7.0E-01	H	7.0E-01	HEAST	7.0E-01	Calc	1.0E+00	PROV	1	0.00
Xylenes		NC	-	NC	-	NC	-	2.0E-01	I	2.0E-01	Calc	1.0E-01	I	4.0E-01	PROV	4.0E-01	Calc	4.0E-01	PROV	1	0.00
SVOCs																					
1-Methylnaphthalene		2.9E-02	P	2.9E-02	Calc	NC	-	7.0E-02	A	7.0E-02	Calc	NA	-	7.0E-02	Chronic	7.0E-02	Calc	NA	Chronic	1	0.00
2-Methylnaphthalene		NC	-	NC	-	NC	-	4.0E-03	I	4.0E-03	Calc	NA	-	4.0E-03	PROV	4.0E-03	Calc	NA	Chronic	1	0.00
Bis(2-ethylhexyl)phthalate		1.4E-02	I	1.4E-02	Calc	2.4E-06	C	2.0E-02	I	2.0E-02	Calc	NA	-	2.0E-02	Chronic	2.0E-02	Calc	NA	Chronic	1	0.10
Dibenzofuran		NC	-	NC	-	NC	-	1.0E-03	X	1.0E-03	Calc	NA	-	4.0E-03	PROV	4.0E-03	Calc	NA	Chronic	1	0.00
PAHs																					
Acenaphthylene		NC	-	NC	-	NC	-	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.13
Anthracene		NC	-	NC	-	NC	-	3.0E-01	I	3.0E-01	Calc	NA	-	1.0E+00	PROV	1.0E+00	Calc	NA	Chronic	1	0.13
Benzo (a) anthracene	f	C-TEQ	I	C-TEQ	Calc	C-TEQ	I	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.13
Benzo (a) pyrene	f	7.3E+00	I	7.3E+00	Calc	1.1E-03	C	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.13
Benzo (b) fluoranthene	f	C-TEQ	I	C-TEQ	Calc	C-TEQ	I	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.13
Benzo (g,h,i) perylene		NC	-	NC	-	NC	-	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.13
Benzo (k) fluoranthene	f	C-TEQ	I	C-TEQ	Calc	C-TEQ	I	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.13
Chrysene	f	C-TEQ	I	C-TEQ	Calc	C-TEQ	I	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.13
Dibenzo (a,h) anthracene	f	C-TEQ	I	C-TEQ	Calc	C-TEQ	I	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.13
Fluoranthene		NC	-	NC	-	NC	-	4.0E-02	I	4.0E-02	Calc	NA	-	4.0E-01	HEAST	4.0E-01	Calc	NA	Chronic	1	0.13
Fluorene		NC	-	NC	-	NC	-	4.0E-02	I	4.0E-02	Calc	NA	-	4.0E-01	HEAST	4.0E-01	Calc	NA	Chronic	1	0.13
Indeno (1,2,3-cd) pyrene	f	C-TEQ	I	C-TEQ	Calc	C-TEQ	I	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.13
Naphthalene		NC	-	NC	-	3.4E-05	C	2.0E-02	I	2.0E-02	Calc	3.0E-03	I	2.0E-02	Chronic	2.0E-02	Calc	3.0E-03	Chronic	1	0.13
Phenanthrene		NC	-	NC	-	NC	-	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.13
Pyrene		NC	-	NC	-	NC	-	3.0E-02	I	3.0E-02	Calc	NA	-	3.0E-01	PROV	3.0E-01	Calc	NA	Chronic	1	0.13
Total Benzo(a)pyrene TEQ	f	7.3E+00	I	7.3E+00	Calc	1.1E-03	C	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.13
Miscellaneous																					
Cyanide		NC	-	NC	-	NC	-	2.0E-02	I	2.0E-02	Calc	NA	-	2.0E-02	HEAST	2.0E-02	Calc	NA	Chronic	1	0.00
Sulfate		NC	-	NC	-	NC	-	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	0.00
Sulfolane	d	NC	-	NC	-	NC	-	1.0E-03	PPRTV	1.0E-03	Calc	NA	-	1.0E-02	PPRTV	1.0E-02	Calc	NA	Chronic	1	0.00
Sulfolane	d	NC	-	NC	-	NC	-	1.0E-02	ARCADIS	1.0E-02	Calc	NA	-	1.0E-01	ARCADIS	1.0E-01	Calc	NA	Chronic	1	0.00
GRO	e	NC	-	NC	-	NC	-	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	NA
DRO	e	NC	-	NC	-	NC	-	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	NA
RRO	e	NC	-	NC	-	NC	-	NA	-	NA	Calc	NA	-	NA	Chronic	NA	Calc	NA	Chronic	1	NA

Table 3-13
Human Health Toxicity Values

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Notes:
ABSd = dermal absorption factor, obtained from CalEPA (1999) *Preliminary Endangerment Assessment Manual*
ABSo = oral absorption factor, obtained from USEPA (2004) *Risk Assessment Guidance for Superfund* , Part E
ARCADIS = Literature-derived toxicity value, as presented in the main text.
A = Agency for Toxic Substances and Disease Registry (ATSDR) as cited in the USEPA (2011) RSLs
C = CalEPA Office of Environmental Health Hazard Asssessment (OEHHA) Toxicity Criteria Database
C-TEQ = carcingogenic PAH evaluated using Benzo(a)pyrene TEQ. See footnote "c" below.
Calc = calculated using oral absorption fraction folllowing USEPA (2004) *Risk Assessment Guidelines for Superfund* , Part E.
CSFd = dermal cancer slope factor
CSFo = oral cancer slope factor
DRO = diesel range organic
GRO = gasoline range organic
H = HEAST Tables, as cited in the USEPA (2011) RSLs
HEAST = Health Effects Assessment Summary Tables (HEAST; USEPA, 1997) as cited in the USEPA (2011) Risk Assessment Information System (RAIS) database
I = Integrated Risk Information System (IRIS)
IUR = inhalation unit risk
kg = kilogram(s)
m^3 = cubic meter(s)
mg = milligram(s)
µg = microgram(s)
NA = value not available
NC = not classified by USEPA as a carinogen by the specific exposure route
NE = not evaluated using dose-based toxicity values
PAH = polycyclic aromatic hydrocarbon
PPRTV = Final Peer-Reviewed Toxicity Value for Sulfolane. (USEPA, 2012)
PROV = Provisional Peer-Reviewed Toxicity Values (PPRTVs) as cited in the USEPA (2011) Risk Assessment Information System (RAIS) database
P = Provisional Peer-Reviewed Toxicity Values (PPRTVs) as cited in the USEPA (2011) RSLs
RfC = reference concentration
RfDd = dermal reference dose
RfDo = oral reference dose
RRO = residual range organic
SVOC = semi-volatile organic compound
VOC = volatile organic compound
X = PPRTV Appendix as cited in the USEPA (2011) RSLs
-- = not available

a. Cadmium toxicity values for dietary exposure are used.
b. Toxicity values for Chromium III are used for total chromium.
c. Lead evaluated separately using USEPA exposure models.
d. Sulfolane toxicity values from PPRTV (USEPA, 2012) used in the PPRTV Scenario evaluation, toxicity values derived by ARCADIS from the literature used in the ARCADIS Scenario.
e. Total petroluem hydrocarbon (TPH) mixtures evaluated separately using indicator compounds, as described in Alaska Cumulative Risk Guidance (ADEC, 2008).
f. PAHs considered potential human carcinogens are evaluated in accordance with USEPA (1993) guidance. Accordingly, the estimated "Total Benzo(a)pyrene Toxic Equivalent Concentration" (BaP-TEQ) is evaluated using the toxicity of benzo(a)pyrene

Table 3-14
Human Health Risk Summary for Onsite and Offsite Receptors - UCL and Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on Maximum COPC Concentration [a]				Contributing COPCs	EPC of Contributing COPC					
	PPRTV Scenario										
Potential Site Receptors	ELCR	Contributing COPCs	HI	Contributing COPCs		Groundwater (mg/L)	Soil (mg/kg)	Soil Gas (mg/m^3)	Indoor / Trench Air (mg/m^3)	Produce (mg/kg ww)	EPC Type
ONSITE RECEPTORS											
Onsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Volatiles in Soil Gas											
inhalation of indoor air	1E-05		2E-01		Benzene	2E+01	--	2E+03	2E-02	--	MAX
Soil Gas Total	1E-05	Benzene (93%)	2E-01	--							
Grand Total	**1E-05**	See Soil Gas Total	**2E-01**	--							
Onsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
oral	4E-06		5E-02		Arsenic	--	8E+00	--	--	--	UCL
dermal	6E-07		3E-03		NA	--	--	--	--	--	UCL
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	5E-06	Arsenic (97%)	5E-02	--							
Grand Total	**5E-06**	--	**5E-02**	--							
Onsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Subsurface Soil (0 to 15 ft bgs)											
oral	8E-07		2E-01		NA	--	--	--	--	--	MAX
dermal	5E-08		3E-03		NA	--	--	--	--	--	MAX
inhalation of outdoor air	8E-08		7E-02		NA	--	--	--	--	--	MAX
Soil Total	1E-06	--	3E-01	--							
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	3E-07		6E-02		NA	--	--	--	--	--	MAX
dermal exposure in a trench	4E-06		6E-01		NA	--	--	--	--	--	MAX
inhalation of trench air	3E-04		4.8E+01		Benzene	2E+01	--	--	2E+02	--	MAX
					Ethylbenzene	3E+00	--	--	2E+01	--	MAX
					Naphthalene	3E-01	--	--	2E+00	--	MAX
					Xylenes	1E+01	--	--	1E+02	--	MAX
					1,3,5-Trimethylbenzene	2E-01	--	--	1E+00	--	MAX
Groundwater Total	3E-04	Benzene(92%), Naphthalene (5%), Ethylbenzene (4%) See Inhalation of trench air	4.9E+01	Benzene (64%), Naphthalene (19%), Xylenes (8%), 1,3,5-Trimethylbenzene (4%) See Inhalation of trench air							
Grand Total	**3E-04**	See Groundwater Total (Inhalation of trench air)	**4.9E+01**	See Groundwater Total (Inhalation of trench air)							
Onsite Visitor (Chronic Exposure)											
Exposure to Volatiles in Soil Gas											
inhalation of indoor air	2E-07		2E-03		NA	--	--	--	--	--	MAX
Soil Gas Total	2E-07		2E-03								
Grand Total	**2E-07**	--	**2E-03**	--							
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		NA	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		1.2E+01		Sulfolane	4E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	1.2E+01	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		8E-01		Sulfolane	4E-01	--	--	--	4E-01	MAX
Produce Total	0E+00	--	8E-01	Sulfolane (100%)							
Exposure to Surface Water [b]											
oral	0E+00		3E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-02	--							
Grand Total	**4E-08**	--	**1.3E+01**	See Groundwater Total & Produce Total							

Table 3-14
Human Health Risk Summary for Onsite and Offsite Receptors - UCL and Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on Maximum COPC Concentration [a]				Contributing COPCs	EPC of Contributing COPC					
	PPRTV Scenario										
Potential Site Receptors	ELCR	Contributing COPCs	HI	Contributing COPCs		Groundwater (mg/L)	Soil (mg/kg)	Soil Gas (mg/m^3)	Indoor / Trench Air (mg/m^3)	Produce (mg/kg ww)	EPC Type
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2.8E+01		Sulfolane	4E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	2.8E+01	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		2E+00		Sulfolane	4E-01	--	--	--	4E-01	MAX
Produce Total	0E+00		2E+00	Sulfolane (100%)							
Exposure to Surface Water [b]											
oral	0E+00		2E-01		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-01	--							
Grand Total	**9E-09**	--	**3.1E+01**	See Groundwater Total & Produce Total							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		7E+00		Sulfolane	4E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	7E+00	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		3E-01		NA	--	--	--	--	--	MAX
Produce Total	0E+00	--	3E-01	NA							
Grand Total	**1E-09**	--	**7E+00**	See Groundwater Total							
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		9E+00		Sulfolane	4E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	9E+00	Sulfolane (100%)							
Grand Total	**0E+00**	--	**9E+00**	See Groundwater Total							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		9E+00		Sulfolane	4E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	9E+00	Sulfolane (100%)							
Grand Total	**2E-08**	--	**9E+00**	See Groundwater Total							
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		8E-04		NA	--	--	--	--	--	MAX
Groundwater Total	0E+00	--	8E-04	--							
Grand Total	**0E+00**	--	**8E-04**	--							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		3E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-02	--							
Grand Total	**0E+00**	--	**3E-02**	--							

Table 3-14
Human Health Risk Summary for Onsite and Offsite Receptors - UCL and Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on Maximum COPC Concentration [a]				Contributing COPCs	EPC of Contributing COPC					
	PPRTV Scenario										
Potential Site Receptors	**ELCR**	**Contributing COPCs**	**HI**	**Contributing COPCs**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor / Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-01		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-01	--							
Grand Total	**0E+00**	--	**2E-01**	--							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean

Complete risk and hazard calculations are presented in Appendix D.
[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.
[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix D, Tables D-11 and D-12.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 3-15
Human Health Risk Summary for Onsite Receptors and Offsite Receptors in Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a]				Contributing COPC	EPC of Contributing COPC					
	PPRTV Scenario										
Potential Site Receptors	ELCR	Contributing COPC	HI	Contributing COPC		Groundwater (mg/L)	Soil (mg/kg)	Soil Gas (mg/m^3)	Indoor / Trench Air (mg/m^3)	Produce (mg/kg ww)	EPC Type
ONSITE RECEPTORS											
Onsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Volatiles in Soil Gas											
inhalation of indoor air	1E-06		2E-02		NA	--	--	--	--	--	UCL
Soil Gas Total	1E-06	--	2E-02	--							
Grand Total	**1E-06**	--	**2E-02**	--							
Onsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
oral	4E-06		5E-02		Arsenic	--	8E+00	--	--	--	UCL
dermal	6E-07		3E-03		NA	--	--	--	--	--	UCL
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	5E-06	Arsenic (97%)	5E-02	--							
Grand Total	**5E-06**	--	**5E-02**	--							
Onsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Subsurface Soil (0 to 15 ft bgs)											
oral	3E-07		4E-02		NA	--	--	--	--	--	UCL
dermal	2E-08		3E-04		NA	--	--	--	--	--	UCL
inhalation of outdoor air	1E-08		1E-02		NA	--	--	--	--	--	UCL
Soil Total	3E-07	--	6E-02	--							
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	2E-08		5E-03		NA	--	--	--	--	--	UCL
dermal exposure in a trench	3E-07		8E-02		NA	--	--	--	--	--	UCL
inhalation of trench air	3E-05		9E+00		Naphthalene	1E-01	--	--	1E+00	--	UCL
					Benzene	1E+00	--	--	1E+01	--	UCL
					1,3,5-Trimethylbenzene	1E-01	--	--	9E-01	--	UCL
Groundwater Total	3E-05	Benzene(73%), Naphthalene (24%) See Inhalation of trench air	9E+00	Naphthalene (52%), Benzene (26%), 1,3,5-Trimethylbenzene (15%); See Inhalation of trench air							
Grand Total	**3E-05**	See Groundwater Total	**9E+00**	See Groundwater Total							
Onsite Visitor (Chronic Exposure)											
Exposure to Volatiles in Soil Gas											
inhalation of indoor air	1E-08		2E-04		NA	--	--	--	--	--	UCL
Soil Gas Total	1E-08		2E-04								
Grand Total	**1E-08**	--	**2E-04**	--							
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		NA	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		5E+00		Sulfolane	2E-01	--	--	--	--	UCL
Groundwater Total	0E+00	--	5E+00	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		3E-01		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	3E-01	--							
Exposure to Surface Water [b]											
oral	0E+00		3E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-02	--							
Grand Total	**4E-08**	--	**5E+00**	See Groundwater Total							

Table 3-15
Human Health Risk Summary for Onsite Receptors and Offsite Receptors in Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a]				Contributing COPC	EPC of Contributing COPC					
	PPRTV Scenario										
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor / Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03								
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		1.1E+01		Sulfolane	2E-01	--	--	--	--	UCL
Groundwater Total	0E+00	--	1.1E+01	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		9E-01		Sulfolane	2E-01	--	--	--	2E-01	UCL
Produce Total	0E+00		9E-01	Sulfolane (100%)							
Exposure to Surface Water [b]											
oral	0E+00		2E-01		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-01	--							
Grand Total	**9E-09**	--	**1.2E+01**	See Groundwater Total & Produce Total							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E+00		Sulfolane	2E-01	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E+00	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		1E-01		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	1E-01	--							
Grand Total	**1E-09**	--	**3E+00**	See Groundwater Total							
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E+00		Sulfolane	2E-01	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E+00	Sulfolane (100%)							
Grand Total	**0E+00**	--	**3E+00**	See Groundwater Total							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E+00		Sulfolane	2E-01	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E+00	Sulfolane (100%)							
Grand Total	**2E-08**	--	**3E+00**	See Groundwater Total							

Table 3-15
Human Health Risk Summary for Onsite Receptors and Offsite Receptors in Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a]				Contributing COPC	EPC of Contributing COPC					
	PPRTV Scenario										
Potential Site Receptors	ELCR	Contributing COPC	HI	Contributing COPC		Groundwater (mg/L)	Soil (mg/kg)	Soil Gas (mg/m^3)	Indoor / Trench Air (mg/m^3)	Produce (mg/kg ww)	EPC Type
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		3E-04		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E-04	--							
Grand Total	**0E+00**	--	**3E-04**	--							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		3E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-02	--							
Grand Total	**0E+00**	--	**3E-02**	--							
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-01		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-01	--							
Grand Total	**0E+00**	--	**2E-01**	--							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
EU1 = Exposure Unit 1; defined by a boundary that includes all wells with maximum concentrations greater than 100 ug/L.
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean

Complete risk and hazard calculations are presented in Appendix E.

[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.

[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix D, Tables D-11 and D-12.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 3-16a
Human Health Risk Summary for Offsite Receptors in Exposure Unit 2 - Maximum Groundwater and UCL Soil COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] PPRTV Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor/Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		NA	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		4E+00		Sulfolane	1.44E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	4E+00	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		3E-01		NA	--	--	--	--	--	MAX
Produce Total	0E+00	--	3E-01	--							
Exposure to Surface Water [b]											
oral	0E+00		3E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-02	--							
Grand Total	**4E-08**	--	**4E+00**	See Groundwater Total							
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03								
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		9E+00		Sulfolane	1.44E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	9E+00	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		8E-01		Sulfolane	1.44E-01	--	--	--	1.44E-01	MAX
Produce Total	0E+00		8E-01	Sulfolane (100%)							
Exposure to Surface Water [b]											
oral	0E+00		2E-01		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-01	--							
Grand Total	**9E-09**	--	**1.0E+01**	See Groundwater Total & Produce Total							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E+00		Sulfolane	1.44E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	2E+00	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		1E-01		NA	--	--	--	--	--	MAX
Produce Total	0E+00	--	1E-01	--							
Grand Total	**1E-09**	--	**2E+00**	See Groundwater Total							

Table 3-16a
Human Health Risk Summary for Offsite Receptors in Exposure Unit 2 - Maximum Groundwater and UCL Soil COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] PPRTV Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor/Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E+00		Sulfolane	1.44E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	3E+00	Sulfolane (100%)							
Grand Total	**0E+00**	--	**3E+00**	See Groundwater Total							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E+00		Sulfolane	1.44E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	3E+00	Sulfolane (100%)							
Grand Total	**2E-08**	--	**3E+00**	See Groundwater Total							
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		3E-04		NA	--	--	--	--	--	MAX
Groundwater Total	0E+00	--	3E-04	--							
Grand Total	**0E+00**	--	**3E-04**	--							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		3E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-02	--							
Grand Total	**0E+00**	--	**3E-02**	--							
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-01		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-01	--							
Grand Total	**0E+00**	--	**2E-01**	--							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
EU2 = Exposure Unit 2; defined by a boundary that includes all wells with maximum concentrations greater than 25 ug/L and less than 100 ug/L.
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean

Complete risk and hazard calculations are presented in Appendix D.

[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.

[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix D, Tables D-11 and D-12.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 3-16b
Human Health Risk Summary for Offsite Receptors in Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] PPRTV Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor/Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		NA	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E+00		Sulfolane	5.91E-02	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E+00	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		1E-01		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	1E-01								
Exposure to Surface Water [b]											
oral	0E+00		3E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-02	--							
Grand Total	**4E-08**	--	**2E+00**	See Groundwater Total							
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03								
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		4E+00		Sulfolane	5.91E-02	--	--	--	--	UCL
Groundwater Total	0E+00	--	4E+00	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		3E-01		NA	--	--	--	--	--	UCL
Produce Total	0E+00		3E-01	--							
Exposure to Surface Water [b]											
oral	0E+00		2E-01		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-01	--							
Grand Total	**9E-09**	--	**4E+00**	See Groundwater Total							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		9E-01		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	9E-01	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		4E-02		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	4E-02	--							
Grand Total	**1E-09**	--	**9E-01**	--							

Table 3-16b
Human Health Risk Summary for Offsite Receptors in Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] PPRTV Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor/Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		1E+00		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	1E+00	--							
Grand Total	**0E+00**	--	**1E+00**	--							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		1E+00		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	1E+00	--							
Grand Total	**2E-08**	--	**1E+00**	--							
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		1E-04		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	1E-04	--							
Grand Total	**0E+00**	--	**1E-04**	--							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		3E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-02	--							
Grand Total	**0E+00**	--	**3E-02**	--							
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-01		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-01	--							
Grand Total	**0E+00**	--	**2E-01**	--							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
EU2 = Exposure Unit 2; defined by a boundary that includes all wells with maximum concentrations greater than 25 ug/L and less than 100 ug/L.
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean

Complete risk and hazard calculations are presented in Appendix E.
[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.
[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix D, Tables D-11 and D-12.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 3-17a
Human Health Risk Summary for Offsite Receptors in Exposure Unit 3 - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on Maximum COPC Concentration [a]				Contributing COPC	EPC of Contributing COPC					
	PPRTV Scenario										
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor / Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		NA	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E+00		Sulfolane	8.02E-02	--	--	--	--	MAX
Groundwater Total	0E+00	--	2E+00	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		1E-01		NA	--	--	--	--	--	MAX
Produce Total	0E+00	--	1E-01	--							
Exposure to Surface Water [b]											
oral	0E+00		3E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-02	--							
Grand Total	**4E-08**	--	**2E+00**	See Groundwater Total							
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03								
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		5E+00		Sulfolane	8.02E-02	--	--	--	--	MAX
Groundwater Total	0E+00	--	5E+00	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		4E-01		Sulfolane	8.02E-02	--	--	--	8.02E-02	MAX
Produce Total	0E+00		4E-01	Sulfolane (100%)							
Exposure to Surface Water [b]											
oral	0E+00		2E-01		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-01	--							
Grand Total	**9E-09**	--	**6E+00**	See Groundwater Total and Produce Total							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		1E+00		NA	--	--	--	--	--	MAX
Groundwater Total	0E+00	--	1E+00	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		6E-02		NA	--	--	--	--	--	MAX
Produce Total	0E+00	--	6E-02	--							
Grand Total	**1E-09**	--	**1E+00**	--							

Table 3-17a
Human Health Risk Summary for Offsite Receptors in Exposure Unit 3 - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on Maximum COPC Concentration [a]				Contributing COPC	EPC of Contributing COPC					
	PPRTV Scenario										
Potential Site Receptors	ELCR	Contributing COPC	HI	Contributing COPC		Groundwater (mg/L)	Soil (mg/kg)	Soil Gas (mg/m^3)	Indoor / Trench Air (mg/m^3)	Produce (mg/kg ww)	EPC Type
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E+00		Sulfolane	8.02E-02	--	--	--	--	MAX
Groundwater Total	0E+00	--	2E+00	Sulfolane (100%)							
Grand Total	**0E+00**	--	**2E+00**	See Groundwater Total							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E+00		Sulfolane	8.02E-02	--	--	--	--	MAX
Groundwater Total	0E+00	--	2E+00	Sulfolane (100%)							
Grand Total	**2E-08**	--	**2E+00**	See Groundwater Total							
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		1E-04		NA	--	--	--	--	--	MAX
Groundwater Total	0E+00	--	1E-04	--							
Grand Total	**0E+00**	--	**1E-04**	--							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		3E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-02	--							
Grand Total	**0E+00**	--	**3E-02**	--							
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-01		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-01	--							
Grand Total	**0E+00**	--	**2E-01**	--							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
EU3 = Exposure Unit 3; defined by a boundary that includes all wells with maximum concentrations greater than the detection limit and less than 25 ug/L.
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean
Complete risk and hazard calculations are presented in Appendix D.
[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.
[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix D, Tables D-11 and D-12.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 3-17b
Human Health Risk Summary for Offsite Receptors in Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a]				Contributing COPC	EPC of Contributing COPC					
	PPRTV Scenario										
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor/Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		NA	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E-01		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E-01	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		2E-02		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	2E-02	--							
Exposure to Surface Water [b]											
oral	0E+00		3E-02		NA	**--**	**--**	**--**	**--**	**--**	MAX
Surface Water Total	0E+00	--	3E-02	--							
Grand Total	**4E-08**	--	**3E-01**	--							
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03								
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		7E-01		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	7E-01	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		5E-02		NA	--	--	--	--	--	UCL
Produce Total	0E+00		5E-02	--							
Exposure to Surface Water [b]											
oral	0E+00		2E-01		NA	**--**	**--**	**--**	**--**	**--**	MAX
Surface Water Total	0E+00	--	2E-01	--							
Grand Total	**9E-09**	--	**9E-01**	--							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-01		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E-01	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		7E-03		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	7E-03	--							
Grand Total	**1E-09**	--	**2E-01**	--							

Table 3-17b
Human Health Risk Summary for Offsite Receptors in Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] PPRTV Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor/Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-01		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E-01	--							
Grand Total	**0E+00**	--	**2E-01**	--							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-01		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E-01	--							
Grand Total	**2E-08**	--	**2E-01**	--							
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		2E-05		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E-05	--							
Grand Total	**0E+00**	--	**2E-05**	--							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		3E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-02	--							
Grand Total	**0E+00**	--	**3E-02**	--							
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-01		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-01	--							
Grand Total	**0E+00**	--	**2E-01**	--							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
EU3 = Exposure Unit 3; defined by a boundary that includes all wells with maximum concentrations greater than the detection limit and less than 25 ug/L.
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean

Complete risk and hazard calculations are presented in Appendix E.
[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.
[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix D, Tables D-11 and D-12.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 4-1
Human Health Risk Summary for Onsite and Offsite Receptors - UCL and Maximum Groundwater COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on Maximum COPC Concentration [a] ARCADIS Comparative Scenario				Contributing COPCs	EPC of Contributing COPC					
Potential Site Receptors	ELCR	Contributing COPCs	HI	Contributing COPCs		Groundwater (mg/L)	Soil (mg/kg)	Soil Gas (mg/m^3)	Indoor / Trench Air (mg/m^3)	Produce (mg/kg ww)	EPC Type
ONSITE RECEPTORS											
Onsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Volatiles in Soil Gas											
inhalation of indoor air	1E-05		2E-01		Benzene	2E+01	--	2E+03	2E-02	--	MAX
Soil Gas Total	1E-05	Benzene (93%)	2E-01	--							
Grand Total	**1E-05**	See Soil Gas Total	**2E-01**	--							
Onsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
oral	4E-06		5E-02		Arsenic	--	8E+00	--	--	--	UCL
dermal	6E-07		3E-03		NA	--	--	--	--	--	UCL
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	5E-06	Arsenic (97%)	5E-02	--							
Grand Total	**5E-06**	--	**5E-02**	--							
Onsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Subsurface Soil (0 to 15 ft bgs)											
oral	8E-07		2E-01		NA	--	--	--	--	--	MAX
dermal	5E-08		3E-03		NA	--	--	--	--	--	MAX
inhalation of outdoor air	8E-08		7E-02		NA	--	--	--	--	--	MAX
Soil Total	1E-06	--	3E-01	--							
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	3E-07		4E-02		NA	--	--	--	--	--	MAX
dermal exposure in a trench	4E-06		6E-01		NA	--	--	--	--	--	MAX
inhalation of trench air	3E-04		4.8E+01		Benzene	2E+01	--	--	2E+02	--	MAX
					Ethylbenzene	3E+00	--	--	2E+01	--	MAX
					Naphthalene	3E-01	--	--	2E+00	--	MAX
					Xylenes	1E+01	--	--	1E+02	--	MAX
					1,3,5-Trimethylbenzene	2E-01	--	--	1E+00	--	MAX
Groundwater Total	3E-04	Benzene(92%), Naphthalene (5%), Ethylbenzene (4%) See Inhalation of trench air	4.9E+01	Benzene (64%), Naphthalene (19%), Xylenes (8%), 1,3,5-Trimethylbenzene (4%) See Inhalation of trench air							
Grand Total	**3E-04**	See Groundwater Total (Inhalation of trench air)	**4.9E+01**	See Groundwater Total (Inhalation of trench air)							
Onsite Visitor (Chronic Exposure)											
Exposure to Volatiles in Soil Gas											
inhalation of indoor air	2E-07		2E-03		NA	--	--	--	--	--	MAX
Soil Gas Total	2E-07		2E-03								
Grand Total	**2E-07**	--	**2E-03**	--							
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		NA	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		1.2E+00		Sulfolane	4E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	1.2E+00	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		8E-02		Sulfolane	4E-01	--	--	--	4E-01	MAX
Produce Total	0E+00	--	8E-02	Sulfolane (100%)							
Exposure to Surface Water [b]											
oral	0E+00		3E-03		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-03	--							
Grand Total	**4E-08**	--	**1.3E+00**	See Groundwater Total & Produce Total							

Table 4-1
Human Health Risk Summary for Onsite and Offsite Receptors - UCL and Maximum Groundwater COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on Maximum COPC Concentration [a] ARCADIS Comparative Scenario				Contributing COPCs	EPC of Contributing COPC					
Potential Site Receptors	ELCR	Contributing COPCs	HI	Contributing COPCs		Groundwater (mg/L)	Soil (mg/kg)	Soil Gas (mg/m^3)	Indoor / Trench Air (mg/m^3)	Produce (mg/kg ww)	EPC Type
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2.8E+00		Sulfolane	4E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	2.8E+00	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		2E-01		Sulfolane	4E-01	--	--	--	4E-01	MAX
Produce Total	0E+00		2E-01	Sulfolane (100%)							
Exposure to Surface Water [b]											
oral	0E+00		2E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-02	--							
Grand Total	**9E-09**	--	**3.1E+00**	See Groundwater Total & Produce Total							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		7E-01		Sulfolane	4E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	7E-01	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		3E-02		NA	--	--	--	--	--	MAX
Produce Total	0E+00	--	3E-02	NA							
Grand Total	**1E-09**	--	**7E-01**	See Groundwater Total							
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		9E-01		Sulfolane	4E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	9E-01	Sulfolane (100%)							
Grand Total	**0E+00**	--	**9E-01**	See Groundwater Total							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		9E-01		Sulfolane	4E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	9E-01	Sulfolane (100%)							
Grand Total	**2E-08**	--	**9E-01**	See Groundwater Total							
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		8E-05		NA	--	--	--	--	--	MAX
Groundwater Total	0E+00	--	8E-05	--							
Grand Total	**0E+00**	--	**8E-05**	--							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		3E-03		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-03	--							
Grand Total	**0E+00**	--	**3E-03**	--							

Table 4-1
Human Health Risk Summary for Onsite and Offsite Receptors - UCL and Maximum Groundwater COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on Maximum COPC Concentration [a] ARCADIS Comparative Scenario				Contributing COPCs	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPCs**	**HI**	**Contributing COPCs**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor / Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-02	--							
Grand Total	**0E+00**	--	**2E-02**	--							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean

Complete risk and hazard calculations are presented in Appendix D.
[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.
[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix D, Tables D-35 and D-36.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 4-2
Human Health Risk Summary for Onsite Receptors and Offsite Receptors in Exposure Unit 1 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a]				Contributing COPC	EPC of Contributing COPC					
	Arcadis Comparative Scenario										
Potential Site Receptors	ELCR	Contributing COPC	HI	Contributing COPC		Groundwater (mg/L)	Soil (mg/kg)	Soil Gas (mg/m^3)	Indoor / Trench Air (mg/m^3)	Produce (mg/kg ww)	EPC Type
ONSITE RECEPTORS											
Onsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Volatiles in Soil Gas											
inhalation of indoor air	1E-06		2E-02		NA	--	--	--	--	--	UCL
Soil Gas Total	1E-06	--	2E-02	--							
Grand Total	**1E-06**	--	**2E-02**	--							
Onsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
oral	4E-06		5E-02		Arsenic	--	8E+00	--	--	--	UCL
dermal	6E-07		3E-03		NA	--	--	--	--	--	UCL
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	5E-06	Arsenic (97%)	5E-02	--							
Grand Total	**5E-06**	--	**5E-02**	--							
Onsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Subsurface Soil (0 to 15 ft bgs)											
oral	3E-07		4E-02		NA	--	--	--	--	--	UCL
dermal	2E-08		3E-04		NA	--	--	--	--	--	UCL
inhalation of outdoor air	1E-08		1E-02		NA	--	--	--	--	--	UCL
Soil Total	3E-07	--	6E-02	--							
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	2E-08		4E-03		NA	--	--	--	--	--	UCL
dermal exposure in a trench	3E-07		8E-02		NA	--	--	--	--	--	UCL
inhalation of trench air	3E-05		9E+00		Naphthalene	1E-01	--	--	1E+00	--	UCL
					Benzene	1E+00	--	--	1E+01	--	UCL
					1,3,5-Trimethylbenzene	1E-01	--	--	9E-01	--	UCL
Groundwater Total	3E-05	Benzene(73%), Naphthalene (24%) See Inhalation of trench air	9E+00	Naphthalene (52%), Benzene (26%), 1,3,5-Trimethylbenzene (15%); See Inhalation of trench air							
Grand Total	**3E-05**	See Groundwater Total	**9E+00**	See Groundwater Total							
Onsite Visitor (Chronic Exposure)											
Exposure to Volatiles in Soil Gas											
inhalation of indoor air	1E-08		2E-04		NA	--	--	--	--	--	UCL
Soil Gas Total	1E-08		2E-04								
Grand Total	**1E-08**	--	**2E-04**	--							
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		NA	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		5E-01		Sulfolane	2E-01	--	--	--	--	UCL
Groundwater Total	0E+00	--	5E-01	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		3E-02		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	3E-02	--							
Exposure to Surface Water [b]											
oral	0E+00		3E-03		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-03	--							
Grand Total	**4E-08**	--	**5E-01**	See Groundwater Total							

Table 4-2
Human Health Risk Summary for Onsite Receptors and Offsite Receptors in Exposure Unit 1 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a]				Contributing COPC	EPC of Contributing COPC					
	Arcadis Comparative Scenario										
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor / Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03								
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		1.1E+00		Sulfolane	2E-01	--	--	--	--	UCL
Groundwater Total	0E+00	--	1.1E+00	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		9E-02		Sulfolane	2E-01	--	--	--	2E-01	UCL
Produce Total	0E+00		9E-02	Sulfolane (100%)							
Exposure to Surface Water [b]											
oral	0E+00		2E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-02	--							
Grand Total	**9E-09**	--	**1.2E+00**	See Groundwater Total & Produce Total							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E-01		Sulfolane	2E-01	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E-01	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		1E-02		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	1E-02	--							
Grand Total	**1E-09**	--	**3E-01**	See Groundwater Total							
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E-01		Sulfolane	2E-01	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E-01	Sulfolane (100%)							
Grand Total	**0E+00**	--	**3E-01**	See Groundwater Total							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E-01		Sulfolane	2E-01	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E-01	Sulfolane (100%)							
Grand Total	**2E-08**	--	**3E-01**	See Groundwater Total							

Table 4-2
Human Health Risk Summary for Onsite Receptors and Offsite Receptors in Exposure Unit 1 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a]				Contributing COPC	EPC of Contributing COPC					
	Arcadis Comparative Scenario										
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor / Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		3E-05		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E-05	--							
Grand Total	**0E+00**	--	**3E-05**	--							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		3E-03		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-03	--							
Grand Total	**0E+00**	--	**3E-03**	--							
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-02	--							
Grand Total	**0E+00**	--	**2E-02**	--							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
EU1 = Exposure Unit 1; defined by a boundary that includes all wells with maximum concentrations greater than 100 ug/L.
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean

Complete risk and hazard calculations are presented in Appendix E.

[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.

[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix D, Tables D-35 and D-36.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 4-3a
Human Health Risk Summary for Offsite Receptors in Exposure Unit 2 - Maximum Groundwater and UCL Soil COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Potential Site Receptors	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] ARCADIS Comparative Scenario				Contributing COPC	EPC of Contributing COPC					
	ELCR	Contributing COPC	HI	Contributing COPC		Groundwater (mg/L)	Soil (mg/kg)	Soil Gas (mg/m^3)	Indoor/Trench Air (mg/m^3)	Produce (mg/kg ww)	EPC Type
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		NA	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		4E-01		Sulfolane	1.44E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	4E-01	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		3E-02		NA	--	--	--	--	--	MAX
Produce Total	0E+00	--	3E-02	--							
Exposure to Surface Water [b]											
oral	0E+00		3E-03		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-03	--							
Grand Total	**4E-08**	--	**4E-01**	See Groundwater Total							
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03								
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		9E-01		Sulfolane	1.44E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	9E-01	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		8E-02		Sulfolane	1.44E-01	--	--	--	1.44E-01	MAX
Produce Total	0E+00		8E-02	Sulfolane (100%)							
Exposure to Surface Water [b]											
oral	0E+00		2E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-02	--							
Grand Total	**9E-09**	--	**1.0E+00**	See Groundwater Total & Produce Total							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-01		Sulfolane	1.44E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	2E-01	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		1E-02		NA	--	--	--	--	--	MAX
Produce Total	0E+00	--	1E-02	--							
Grand Total	**1E-09**	--	**2E-01**	See Groundwater Total							

Table 4-3a
Human Health Risk Summary for Offsite Receptors in Exposure Unit 2 - Maximum Groundwater and UCL Soil COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] ARCADIS Comparative Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor/Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E-01		Sulfolane	1.44E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	3E-01	Sulfolane (100%)							
Grand Total	**0E+00**	--	**3E-01**	See Groundwater Total							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E-01		Sulfolane	1.44E-01	--	--	--	--	MAX
Groundwater Total	0E+00	--	3E-01	Sulfolane (100%)							
Grand Total	**2E-08**	--	**3E-01**	See Groundwater Total							
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		3E-05		NA	--	--	--	--	--	MAX
Groundwater Total	0E+00	--	3E-05	--							
Grand Total	**0E+00**	--	**3E-05**	--							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		3E-03		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-03	--							
Grand Total	**0E+00**	--	**3E-03**	--							
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-02	--							
Grand Total	**0E+00**	--	**2E-02**	--							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
EU2 = Exposure Unit 2; defined by a boundary that includes all wells with maximum concentrations greater than 25 ug/L and less than 100 ug/L.
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean

Complete risk and hazard calculations are presented in Appendix D.
[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.
[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix D, Tables D-35 and D-36.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 4-3b
Human Health Risk Summary for Offsite Receptors in Exposure Unit 2 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] ARCADIS Comparative Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	ELCR	Contributing COPC	HI	Contributing COPC		Groundwater (mg/L)	Soil (mg/kg)	Soil Gas (mg/m^3)	Indoor/Trench Air (mg/m^3)	Produce (mg/kg ww)	EPC Type
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		NA	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-01		Sulfolane	5.91E-02	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E-01	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		1E-02		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	1E-02								
Exposure to Surface Water [b]											
oral	0E+00		3E-03		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-03	--							
Grand Total	**4E-08**	--	**2E-01**	See Groundwater Total							
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03								
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		4E-01		Sulfolane	5.91E-02	--	--	--	--	UCL
Groundwater Total	0E+00	--	4E-01	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		3E-02		NA	--	--	--	--	--	UCL
Produce Total	0E+00		3E-02	--							
Exposure to Surface Water [b]											
oral	0E+00		2E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-02	--							
Grand Total	**9E-09**	--	**4E-01**	See Groundwater Total							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		9E-02		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	9E-02	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		4E-03		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	4E-03	--							
Grand Total	**1E-09**	--	**9E-02**	--							

Table 4-3b
Human Health Risk Summary for Offsite Receptors in Exposure Unit 2 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] ARCADIS Comparative Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor/Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		1E-01		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	1E-01	--							
Grand Total	**0E+00**	--	**1E-01**	--							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		1E-01		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	1E-01	--							
Grand Total	**2E-08**	--	**1E-01**	--							
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		1E-05		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	1E-05	--							
Grand Total	**0E+00**	--	**1E-05**	--							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		3E-03		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-03	--							
Grand Total	**0E+00**	--	**3E-03**	--							
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-02	--							
Grand Total	**0E+00**	--	**2E-02**	--							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
EU2 = Exposure Unit 2; defined by a boundary that includes all wells with maximum concentrations greater than 25 ug/L and less than 100 ug/L.
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean

Complete risk and hazard calculations are presented in Appendix E.
[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.
[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix D, Tables D-35 and D-36.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 4-4a
Human Health Risk Summary for Offsite Receptors in Exposure Unit 3 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on Maximum COPC Concentration [a]				Contributing COPC	EPC of Contributing COPC					
	ARCADIS Comparative Scenario										
Potential Site Receptors	ELCR	Contributing COPC	HI	Contributing COPC		Groundwater (mg/L)	Soil (mg/kg)	Soil Gas (mg/m^3)	Indoor / Trench Air (mg/m^3)	Produce (mg/kg ww)	EPC Type
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		NA	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-01		Sulfolane	8.02E-02	--	--	--	--	MAX
Groundwater Total	0E+00	--	2E-01	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		1E-02		NA	--	--	--	--	--	MAX
Produce Total	0E+00	--	1E-02	--							
Exposure to Surface Water [b]											
oral	0E+00		3E-03		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-03	--							
Grand Total	**4E-08**	--	**2E-01**	See Groundwater Total							
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03								
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		5E-01		Sulfolane	8.02E-02	--	--	--	--	MAX
Groundwater Total	0E+00	--	5E-01	Sulfolane (100%)							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		4E-02		Sulfolane	8.02E-02	--	--	--	8.02E-02	MAX
Produce Total	0E+00		4E-02	Sulfolane (100%)							
Exposure to Surface Water [b]											
oral	0E+00		2E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-02	--							
Grand Total	**9E-09**	--	**6E-01**	See Groundwater Total and Produce Total							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		1E-01		NA	--	--	--	--	--	MAX
Groundwater Total	0E+00	--	1E-01	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		6E-03		NA	--	--	--	--	--	MAX
Produce Total	0E+00	--	6E-03	--							
Grand Total	**1E-09**	--	**1E-01**	--							

Table 4-4a
Human Health Risk Summary for Offsite Receptors in Exposure Unit 3 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on Maximum COPC Concentration [a] ARCADIS Comparative Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	ELCR	Contributing COPC	HI	Contributing COPC		Groundwater (mg/L)	Soil (mg/kg)	Soil Gas (mg/m^3)	Indoor / Trench Air (mg/m^3)	Produce (mg/kg ww)	EPC Type
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-01		Sulfolane	8.02E-02	--	--	--	--	MAX
Groundwater Total	0E+00	--	2E-01	Sulfolane (100%)							
Grand Total	**0E+00**	--	**2E-01**	See Groundwater Total							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-01		Sulfolane	8.02E-02	--	--	--	--	MAX
Groundwater Total	0E+00	--	2E-01	Sulfolane (100%)							
Grand Total	**2E-08**	--	**2E-01**	See Groundwater Total							
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		1E-05		NA	--	--	--	--	--	MAX
Groundwater Total	0E+00	--	1E-05	--							
Grand Total	**0E+00**	--	**1E-05**	--							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		3E-03		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-03	--							
Grand Total	**0E+00**	--	**3E-03**	--							
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-02	--							
Grand Total	**0E+00**	--	**2E-02**	--							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
EU3 = Exposure Unit 3; defined by a boundary that includes all wells with maximum concentrations greater than the detection limit and less than 25 ug/L.
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean
Complete risk and hazard calculations are presented in Appendix D.
[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.
[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix D, Tables D-35 and D-36.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 4-4b
Human Health Risk Summary for Offsite Receptors in Exposure Unit 3 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] ARCADIS Comparative Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor/Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		NA	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E-02		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E-02	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		2E-03		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	2E-03	--							
Exposure to Surface Water [b]											
oral	0E+00		3E-03		NA	**--**	**--**	**--**	**--**	**--**	MAX
Surface Water Total	0E+00	--	3E-03	--							
Grand Total	**4E-08**	--	**3E-02**	--							
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03								
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		7E-02		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	7E-02	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		5E-03		NA	--	--	--	--	--	UCL
Produce Total	0E+00		5E-03	--							
Exposure to Surface Water [b]											
oral	0E+00		2E-02		NA	**--**	**--**	**--**	**--**	**--**	MAX
Surface Water Total	0E+00	--	2E-02	--							
Grand Total	**9E-09**	--	**9E-02**	--							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-02		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E-02	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		7E-04		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	7E-04	--							
Grand Total	**1E-09**	--	**2E-02**	--							

Table 4-4b
Human Health Risk Summary for Offsite Receptors in Exposure Unit 3 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] ARCADIS Comparative Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor/Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-02		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E-02	--							
Grand Total	**0E+00**	--	**2E-02**	--							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-02		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E-02	--							
Grand Total	**2E-08**	--	**2E-02**	--							
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		2E-06		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E-06	--							
Grand Total	**0E+00**	--	**2E-06**	--							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		3E-03		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	3E-03	--							
Grand Total	**0E+00**	--	**3E-03**	--							
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-02		NA	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-02	--							
Grand Total	**0E+00**	--	**2E-02**	--							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
EU3 = Exposure Unit 3; defined by a boundary that includes all wells with maximum concentrations greater than the detection limit and less than 25 ug/L.
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean

Complete risk and hazard calculations are presented in Appendix E.
[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.
[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix D, Tables D-35 and D-36.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 4-5
Human Health Exposure Parameters - ARCADIS Exposure Assumptions

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	Symbol	Units	Onsite and Offsite Commercial/Industrial Indoor Worker		Onsite Commercial/Industrial Outdoor Worker		Onsite and Offsite Construction/Trench Worker		Onsite Adult Visitor		Offsite Adult Resident		Offsite Child (1-6 yr) Resident		Offsite Infant (0-1 yr) Resident		Offsite Adult Recreator		Offsite Child (1-6 yr) Recreator	
			CI		CIo		CST		VIS		ADUR		CHR		INF		AREC		CREC	
General Factors																				
Averaging Time (cancer)	ATc	days	25,550	a,b	25,550	a,b	25,550	a	25,550	a	25,550	a,b	25,550	a,b	25,550	a,b	25,550	a,b	25,550	a,b
Averaging Time (noncancer)	ATnc	days	9,125	a	9,125	a	365	a	10,950	a	10,950	a	2,190	a	365	a	10,950	a	2,190	a
Body Weight	BW	kg	70	b, d	70	b, d	70	d, f	70	b	70	b, d	15	b,d	6.75	n	70	b, d	15	o
Exposure Frequency - Soil	EF	days/yr	250	b, c	250	b, c	125	d, f	12	PJ	270	b, c	270	b, c	270	b,d	–		–	
Exposure Frequency - Groundwater	EFgw	days/year	250	b, c	250	b, c	125	d, f	12	PJ	350	b	350	b	350	b,d	–		–	
Exposure Frequency - Surface water	EFsw	days/year	–		–		–		–		30	PJ	30	PJ	–		30	PJ	30	PJ
Exposure Duration	ED	years	25	b	25	b	1	PJ	30	b	30	b	6	b	1	n	30	b	6	b
Exposure Time	ET	hr/day	8	PJ	8	PJ	1	PJ	2	PJ	12	PJ	12	PJ	12	PJ	0.5	PJ	0.5	PJ
Groundwater - Ingestion (Oral)																				
Groundwater Ingestion Rate (drinking water)	IRgw	L/day	2	b	2	b	–		–		2	b	1	d	1.05	l				
Groundwater Ingestion Rate (incidental)	IRinc_gw	L/day	–		–		0.0037	m	–		–		–		–		–		–	
Fraction Ingested from Source	Figw	unitless	1	cons	1	cons	1	cons	–		1	cons	1	cons	1	cons	–		–	
Groundwater - Dermal Contact																	–		–	
Exposed Skin Surface Area	SSAgw	cm^2	–		–		2,230	k	–		–		–		–					
Event Frequency	EvFgw	events/day	–		–		1	--	–		–		–		–		–		–	
Event Time	EvTgw	hr/event	–		–		1	PJ	–		–		–		–		–		–	
Groundwater - Inhalation of Volatiles																	–		–	
Exposure Frequency - Trench Air	EFtr	days/year	–		–		125	PJ	–		–		–		–		–		–	
Soil - Ingestion (Oral)																	–		–	
Incidental Soil Ingestion Rate	IRs	mg/day	–		100	b, f	330	i	–		–		–		–		–		–	
Fraction Ingested from Source	FI	unitless	–		1	--	1	cons	–		–		–		–		–		–	
Soil - Dermal Contact																	–		–	
Exposed Skin Surface Area	SA	cm^2	–		2,230	k	2,230	k	–		–		–		–		1	b	1	b
Skin Adherence Factor	AF	mg/cm^2-day	–		0.2	b, h	0.3	i	–		–		–		–		–		–	
Fraction in Contact with Soil	FC	unitless	–		1	b	1	b	–		–		–		–		–		–	
Event Frequency	EvFs	events/day	–		1	--	1	--	–		–		–		–		–		–	
Soil - Inhalation of Dust and Vapor																	–		–	
Particulate Emission Factor	PEF	m^3/kg	–		1.32E+09	b,e	1.00E+06	e,j	–		1.32E+09	b,e	1.32E+09	e	1.32E+09	e	–		–	
Homegrown Produce Ingestion																				
Fruit Ingestion Rate	IRPfr	mg/day	–		–		–		–		63,000	g	69,000	g	41,850	g				
Vegetable Ingestion Rate	IRPvg	mg/day	–		–		–		–		175,000	g	81,000	g	33,750	g	–		–	
Fraction Ingested from Source	FIp	unitless	–		–		–		–		0.25	PJ	0.25	PJ	0.25	PJ	–		–	
Bioconcentration Factor	BCF	L/kg ww									0.32	q	0.32	q	0.32	q	–		–	
Surface water - Ingestion (Oral)																				
Surface water Ingestion Rate (incidental)	IRinc_sw	L/hour									0.021	p	0.049	p			0.021	p	0.049	p
Fraction Ingested from Source	Fisw	unitless									1	cons	1	cons			1	cons	1	cons

Table 4-5
Human Health Exposure Parameters - ARCADIS Exposure Assumptions

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Notes:

a. The averaging period for cancer risk is the expected lifespan of 70 years expressed in days (70 years * 365 days/year). The averaging period for non-cancer risk is the total exposure period expressed in days (ED * 365 days/year).
b. ADEC (2010). Risk Assessmenet Procedures Manual. July.
c. Soil exposure frequency is based on the climate zone in which the site is located, consistent with ADEC's Cleanup Level Guidance (DEC 2008). Residential and recreation/subsistence user soil exposure frequency is 270 d/yr for the under 40-inch zone. For commercial/industrial workers the soil exposure frequency is 250 d/yr for the
d. USEPA. 1989. Risk Assessment Guidance for Superfund.Volume I, Human Health Evaluation Manual (Part A) . EPA/540/1-89-002. December.
e. CALEPA. 2011. Human Health RIsk Assessment Note 1. Recommended DTSC Default Exposure Factors for Use in Risk Assessment at California Hazardous Waste Sites and Permitted Facilities. May.
f. USEPA. 1991. Standard Default Exposure Factors, Interim Final . OSWER Directive: 9285.6-03. March.
g. USEPA (2011). Exposure Factors Handbook. For fruit: Table 9-3, mean per capita intake (value for ages 3-5 years used for child). For vegetables: Table 9-5, mean per capita intake of leafy vegetables (value for ages 3-5 years used for child). IRPs in EFH were multiplied by body weight.
h. USEPA (2004). Risk Assessment Guidance for Superfund, Vol 1, Part E, Supplemental Guidance for Dermal Risk Assessment. Office of Emergency and Remedial
i. USEPA (2002a). Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. OSWER 9355.4-24. December.
j. This PEF value corresponds to a respirable dust concentration of 1 mg/m3. This is based on a maximum concentration of dust in air of 10 mg/m3 recommended by the American Conference of Governmental Industrial Hygienists (ACGIH 2004, Threshold Limit Values and Biological Exposure Indices), and the assumption that 10 percent of the mass of particles are in the respirable PM10 range.
k. USEPA (2011). Exposure Factors Handbook. Table 7-2, average of adult male and adult female mean values for head and hands.
l. USEPA (2011). Exposure Factors Handbook. Table 3-1, time-weighted 95th percentile ingestion rate for infants.
m. USEPA (2011). Exposure Factors Handbook. Table 3-93, mean incidental ingestion of water during wading/spashing activities.
n. USEPA (2008). Child-Specific Exposure Factors Handbook. EPA/600/R-06/096F. September.
o. See footnotes b and d.
p. USEPA (2011). Exposure Factors Handbook. Recommended mean values for swimmers from Table 3-5.
q. Derived from the literature as described in the main text.

Exposure equations are presented in Section 3 of the main text.
Exposure parameters with alternate values in the PPRTV and ARCADIS Scenarios are highlighted in gray.

cm	Centimeter.
cons	Conservative assumption (see text).
hr	Hour.
kg	Kilogram.
L	liter
m	Meter.
mg	milligrams
PJ	Professional judgement
ww	wet weight
yr	year

Table 4-6
Human Health Risk Summary for Onsite Construction/Trench Worker Receptors - Maximum and UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Potential Site Receptors	Cumulative Risk and Hazard Estimates Based on Maximum and UCL COPC Concentrations [a] ARCADIS Scenario				Contributing COPC	EPC of Contributing COPC					
	ELCR	Contributing COPC	HI	Contributing COPC		Groundwater (mg/L)	Soil (mg/kg)	Soil Gas (mg/m^3)	Indoor / Trench Air (mg/m^3)	Produce (mg/kg ww)	EPC Type
ONSITE RECEPTORS											
Onsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Subsurface Soil (0 to 15 ft bgs)											
oral	8E-07		2E-01		NA	--	--	--	--	--	MAX
dermal	5E-08		3E-03		NA	--	--	--	--	--	MAX
inhalation of outdoor air	8E-08		7E-02		NA	--	--	--	--	--	MAX
Soil Total	1E-06	--	3E-01	--							
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	2E-08		4E-03		NA	--	--	--	--	--	UCL
dermal exposure in a trench	3E-07		8E-02		Benzene	1E+00	--	--	--	--	UCL
inhalation of trench air	3E-05		9E+00		Naphthalene	1E-01	--	--	1E+00	--	UCL
					Benzene	1E+00	--	--	1E+01	--	UCL
					1,3,5-Trimethylbenzene	1E-01	--	--	9E-01	--	UCL
Groundwater Total	3E-05	Benzene(73%), Naphthalene (24%) see inhalation of trench air	9E+00	Naphthalene (52%), Benzene (26%), 1,3,5-Trimethylbenzene (15%); see Inhalation of trench air							
Grand Total	**3E-05**	See Groundwater Total	**9E+00**	See Groundwater Total							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean

Complete risk and hazard calculations are presented in Appendix F.
[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 4-7
Human Health Risk Summary for Onsite Receptors and Offsite Receptors in Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] ARCADIS Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor / Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
ONSITE RECEPTORS											
Onsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Volatiles in Soil Gas											
inhalation of indoor air	1E-06		2E-02		--	--	--	--	--	--	UCL
Soil Gas Total	1E-06	--	2E-02	--							
Grand Total	**1E-06**	--	**2E-02**	--							
Onsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
oral	4E-06		5E-02		Arsenic	--	8E+00	--	--	--	UCL
dermal	6E-07		3E-03		NA	--	--	--	--	--	UCL
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	5E-06	Arsenic (97%)	5E-02	--							
Grand Total	**5E-06**	See Soil Total	**5E-02**	--							
Onsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Subsurface Soil (0 to 15 ft bgs)											
oral	3E-07		4E-02		NA	--	--	--	--	--	UCL
dermal	2E-08		3E-04		NA	--	--	--	--	--	UCL
inhalation of outdoor air	1E-08		1E-02		NA	--	--	--	--	--	UCL
Soil Total	3E-07	--	6E-02	--							
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	2E-08	NA	4E-03		NA	--	--	--	--	--	UCL
dermal exposure in a trench	3E-07	NA	8E-02		NA	--	--	--	--	--	UCL
inhalation of trench air	3E-05		9E+00		Benzene	1E+00	--	--	1E+01	--	UCL
					Naphthalene	1E-01	--	--	1E+00	--	UCL
					1,3,5-Trimethylbenzene	1E-01	--	--	9E-01	--	UCL
Groundwater Total	3E-05	Benzene(73%), Naphthalene (24%) see Inhalation of trench air	9E+00	Naphthalene (52%), Benzene (26%), 1,3,5-Trimethylbenzene (15%) see Inhalation of trench air							
Grand Total	**3E-05**	See Groundwater Total & Inhalation of Trench Air	**9E+00**	See Groundwater Total							
Onsite Visitor (Chronic Exposure)											
Exposure to Volatiles in Soil Gas											
inhalation of indoor air	1E-08		2E-04		--	--	--	--	--	--	UCL
Soil Gas Total	1E-08		2E-04	--							
Grand Total	**1E-08**	--	**2E-04**	NA							
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		--	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		5E-01		--	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	5E-01	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		3E-03		--	--	--	--	--	--	UCL
Produce Total	0E+00	--	3E-03	--							
Exposure to Surface Water [b]											
oral	0E+00		2E-04		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-04	--							
Grand Total	**4E-08**	--	**5E-01**	NA							

Table 4-7
Human Health Risk Summary for Onsite Receptors and Offsite Receptors in Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] ARCADIS Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor / Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		--	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		1E+00		--	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	1E+00	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		1E-02								UCL
Produce Total	0E+00		1E-02	--	--	--	--	--	--	--	
Exposure to Surface Water [b]											
oral	0E+00		2E-03		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-03	--							
Grand Total	**9E-09**	--	**1E+00**	NA							
Offsite Child Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		7E-04		--	--	--	--	--	--	UCL
Soil Total	9E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		1E-01		--	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	1E-01	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		1E-03		--	--	--	--	--	--	UCL
Produce Total	0E+00		1E-03	--							
Exposure to Surface Water [b]											
oral	0E+00		2E-04		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-04	--							
Grand Total	**9E-09**	--	**1E-01**	NA							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		--	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E-01		--	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E-01	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		1E-03		--	--	--	--	--	--	UCL
Produce Total	0E+00	--	1E-03	--							
Grand Total	**1E-09**	--	**3E-01**	NA							
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E-01		--	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E-01	--							
Grand Total	**0E+00**	--	**3E-01**	NA							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		--	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E-01		--	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E-01	--							
Grand Total	**2E-08**	--	**3E-01**	NA							

Table 4-7
Human Health Risk Summary for Onsite Receptors and Offsite Receptors in Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] ARCADIS Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor / Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		3E-05		--	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E-05	--							
Grand Total	**0E+00**	--	**3E-05**	NA							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-04		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-04	--							
Grand Total	**0E+00**	--	**2E-04**	NA							
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-03		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-03	--							
Grand Total	**0E+00**	--	**2E-03**	NA							
Offsite Child Recreator (Subchronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-04		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-04	--							
Grand Total	**0E+00**	--	**2E-04**	NA							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
EU1 = Exposure Unit 1; defined by a boundary that includes all wells with maximum concentrations greater than 100 ug/L.
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean

Complete risk and hazard calculations are presented in Appendix G.
[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.
[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix G, Tables G-11, G-12a, and G-12b.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 4-8
Human Health Risk Summary for Offsite Receptors in Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] ARCADIS Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor/Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		NA	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-01		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E-01	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		1E-03		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	1E-03								
Exposure to Surface Water [b]											
oral	0E+00		2E-04		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-04	--							
Grand Total	**4E-08**	--	**2E-01**	--							
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03								
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		4E-01		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	4E-01	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		3E-03		NA	--	--	--	--	--	UCL
Produce Total	0E+00		3E-03	--							
Exposure to Surface Water [b]											
oral	0E+00		2E-03		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-03	--							
Grand Total	**9E-09**	--	**4E-01**	--							
Offsite Child Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	7E-04								
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		4E-02		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	4E-02	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		3E-04		NA	--	--	--	--	--	UCL
Produce Total	0E+00		3E-04	--							
Exposure to Surface Water [b]											
oral	0E+00		2E-04		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-04	--							
Grand Total	**9E-09**	--	**4E-02**	--							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		9E-02		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	9E-02	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		4E-04		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	4E-04	--							
Grand Total	**1E-09**	--	**9E-02**	--							

Table 4-8
Human Health Risk Summary for Offsite Receptors in Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] ARCADIS Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor/Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		1E-01		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	1E-01	--							
Grand Total	**0E+00**	--	**1E-01**	--							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		1E-01		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	1E-01	--							
Grand Total	**2E-08**	--	**1E-01**	--							
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		1E-05		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	1E-05	--							
Grand Total	**0E+00**	--	**1E-05**	--							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-04		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-04	--							
Grand Total	**0E+00**	--	**2E-04**	NA							
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-03		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-03	--							
Grand Total	**0E+00**	--	**2E-03**	NA							
Offsite Child Recreator (Subchronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-04		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-04	--							
Grand Total	**0E+00**	--	**2E-04**	NA							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
EU2 = Exposure Unit 2; defined by a boundary that includes all wells with maximum concentrations greater than 25 ug/L and less than 100 ug/L.
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean

Complete risk and hazard calculations are presented in Appendix G.
[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.
[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix G, Tables G-11, G-12a, and G-12b.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 4-9
Human Health Risk Summary for Offsite Receptors in Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Potential Site Receptors	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] ARCADIS Scenario				Contributing COPC	EPC of Contributing COPC					
	ELCR	Contributing COPC	HI	Contributing COPC		Groundwater (mg/L)	Soil (mg/kg)	Soil Gas (mg/m^3)	Indoor/Trench Air (mg/m^3)	Produce (mg/kg ww)	EPC Type
OFFSITE RECEPTORS											
Offsite Adult Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	4E-08		1E-03		NA	--	--	--	--	--	UCL
Soil Total	4E-08	--	1E-03	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		3E-02		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	3E-02	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		2E-04		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	2E-04	--							
Exposure to Surface Water [b]											
oral	0E+00		2E-04		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-04	--							
Grand Total	**4E-08**	--	**3E-02**	--							
Offsite Child Resident (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		1E-03		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	1E-03								
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		7E-02		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	7E-02	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		6E-04		NA	--	--	--	--	--	UCL
Produce Total	0E+00		6E-04	--							
Exposure to Surface Water [b]											
oral	0E+00		2E-03		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-03	--							
Grand Total	**9E-09**	--	**7E-02**	--							
Offsite Child Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	9E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	9E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		7E-03	--	NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	7E-03	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		6E-05		NA	--	--	--	--	--	UCL
Produce Total	0E+00		6E-05	--							
Exposure to Surface Water [b]											
oral	0E+00		2E-04		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-04	--							
Grand Total	**9E-09**	--	**7E-03**	--							
Offsite Infant Resident (Subchronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	1E-09		7E-04		NA	--	--	--	--	--	UCL
Soil Total	1E-09	--	7E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-02		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E-02	--							
Exposure Via Intake of Food											
ingestion of homegrown produce	0E+00		7E-05		NA	--	--	--	--	--	UCL
Produce Total	0E+00	--	7E-05	--							
Grand Total	**1E-09**	--	**2E-02**	--							

Table 4-9
Human Health Risk Summary for Offsite Receptors in Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

	Cumulative Risk and Hazard Estimates Based on UCL COPC Concentration [a] ARCADIS Scenario				Contributing COPC	EPC of Contributing COPC					
Potential Site Receptors	**ELCR**	**Contributing COPC**	**HI**	**Contributing COPC**		**Groundwater (mg/L)**	**Soil (mg/kg)**	**Soil Gas (mg/m^3)**	**Indoor/Trench Air (mg/m^3)**	**Produce (mg/kg ww)**	**EPC Type**
Offsite Commercial/Industrial Indoor Worker (Chronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-02		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E-02	--							
Grand Total	**0E+00**	--	**2E-02**	--							
Offsite Commercial/Industrial Outdoor Worker (Chronic Exposure)											
Exposure to Surface Soil (0 to 2 ft bgs)											
inhalation of outdoor air	2E-08		6E-04		NA	--	--	--	--	--	UCL
Soil Total	2E-08	--	6E-04	--							
Exposure to Groundwater / Volatiles in Groundwater											
oral	0E+00		2E-02		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E-02	--							
Grand Total	**2E-08**	--	**2E-02**	--							
Offsite Construction/Trench Worker (Subchronic Exposure)											
Exposure to Groundwater / Volatiles in Groundwater											
incidental ingestion	0E+00		2E-06		NA	--	--	--	--	--	UCL
Groundwater Total	0E+00	--	2E-06	--							
Grand Total	**0E+00**	--	**2E-06**	--							
Offsite Adult Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-04		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-04	--							
Grand Total	**0E+00**	--	**2E-04**	NA							
Offsite Child Recreator (Chronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-03		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-03	--							
Grand Total	**0E+00**	--	**2E-03**	NA							
Offsite Child Recreator (Subchronic Exposure)											
Exposure to Surface Water [b]											
oral	0E+00		2E-04		--	--	--	--	--	--	MAX
Surface Water Total	0E+00	--	2E-04	--							
Grand Total	**0E+00**	--	**2E-04**	NA							

Notes:
COPC = Constituent of Potential Concern
ELCR = Excess Lifetime Cancer Risk
EPC = Exposure Point Concentration
EU3 = Exposure Unit 3; defined by a boundary that includes all wells with maximum concentrations greater than the detection limit and less than 25 ug/L.
ft bgs = feet below ground surface
HI = hazard index
NA = not applicable
UCL = Upper confidence limit on the mean

Complete risk and hazard calculations are presented in Appendix G.
[a] ELCRs exceeding $1x10^{-5}$ and HIs exceeding 1 are shown in gray.
[b] Complete risk and hazard calculations for the resident and recreator surface water (swimming) pathway are presented in Appendix G, Tables G-11, G-12a, and G-12b.
Values of 0.0 indicate that the pathway was not evaluated, due to lack of appropriate toxicity values, or no COPCs were selected for that media.
-- = not applicable

Table 5-1
Summary of Human Health Alternative Cleanup Levels for Onsite Receptors

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Exposure Medium	Receptor	Relevant Exposure Pathway(s)	Constituent of Concern	Alternative Cleanup Level	Units	Basis
Groundwater (Onsite)	Onsite Construction Worker	Incidental ingestion of groundwater in a trench, Dermal Contact with Groundwater, Inhalation of Trench Air	Benzene	5.90E-01	mg/L	NC
			Naphthalene	3.18E-02	mg/L	NC
			Xylenes	3.47E+00	mg/L	NC
			1,3,5-Trimethylbenzene	9.24E-02	mg/L	NC

Notes:
C = Cancer endpoint
mg/L = milligram(s) per liter
NC = Noncancer endpoint

See Appendix J for derivation.
ACLs based on cancer endpoint reflect a $1x10^{-5}$ target cancer risk. ACLs based on noncancer endpoint reflect target hazard index of one (1).

Table 5-2
Summary of Human Health Alternative Cleanup Levels for Offsite Residents
Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Exposure Medium	Receptor	Relevant Exposure Pathway(s)	Constituent of Concern	Alternative Cleanup Level -- PPRTV Scenario	Alternative Cleanup Level -- ARCADIS Comparative Scenario[1]	Alternative Cleanup Level -- ARCADIS Scenario[2]	Units	Basis
Groundwater (Offsite)	Infant (0-1 yr) -- Subchronic	Ingestion of Groundwater and Ingestion of Produce	Sulfolane	0.064	0.637	0.664	mg/L	NC
	Child (1-6 yrs) -- Chronic			0.014	0.145	0.155	mg/L	NC
	Child (1-6 yrs) -- Subchronic			--	--	1.550	mg/L	NC
	Adult -- Chronic			0.034	0.343	0.362	mg/L	NC

Notes:
NC = Not Carcinogenic
PPRTV = Provisional Peer Reviewed Toxicity Value
mg/L = milligrams per liter
RfD = Reference Dose
[1] ARCADIS Comparative Scenario assumes ARCADIS RfD plus ADEC-approved exposure assumptions
[2] ARCADIS Scenario assumes ARCADIS RfD plus ARCADIS exposure assumptions

See Appendix J (Tables J-2, J-3, and J-4) for derivation.
ACLs based on noncancer endpoint reflect target hazard index of one (1).

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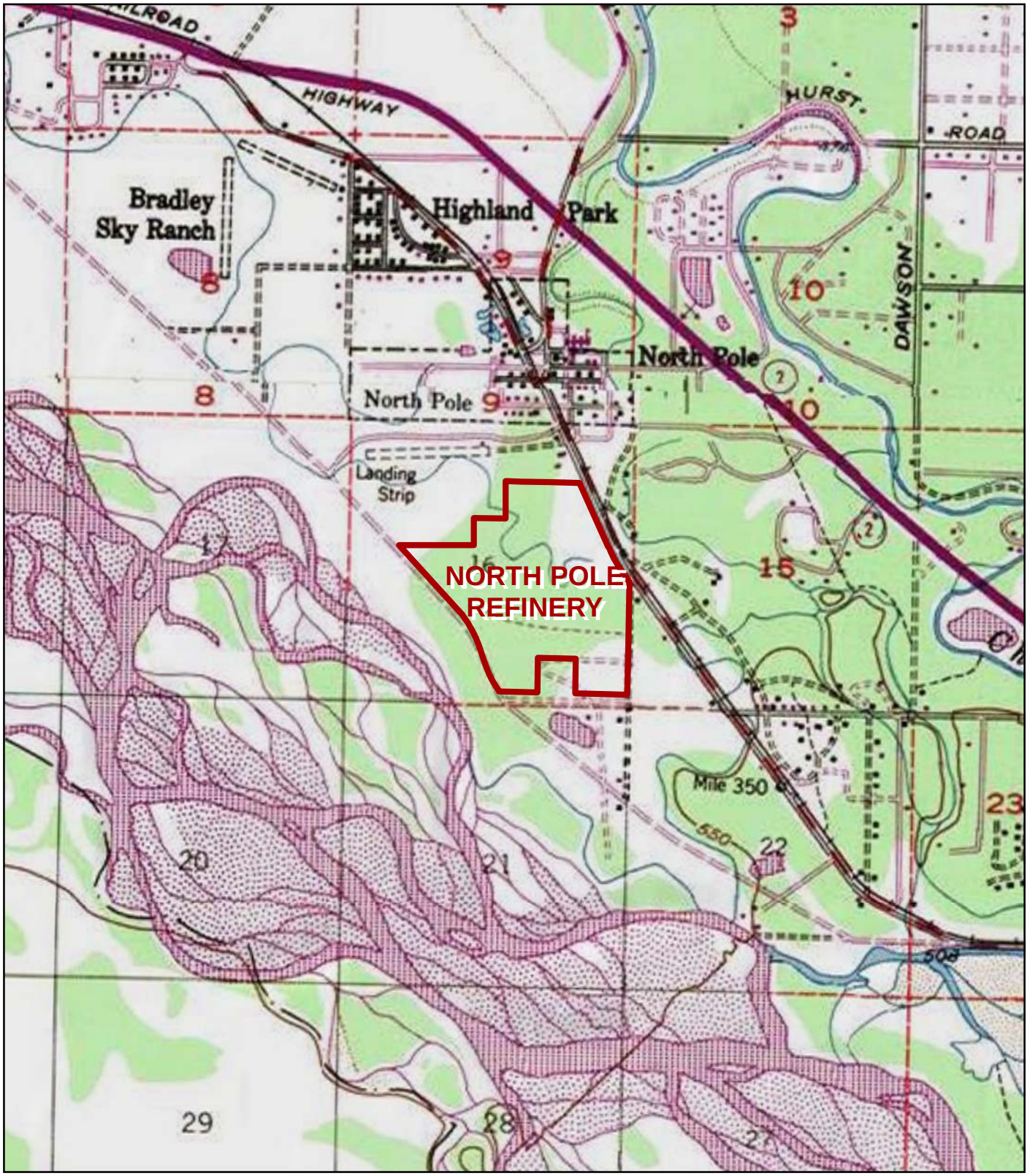
Figures



LEGEND:

FHRA PROPERTY BOUNDARY

0 0.5 Miles

GRAPHIC SCALE

FLINT HILLS RESOURCES ALASKA, LLC
NORTH POLE REFINERY, NORTH POLE, ALASKA

HUMAN HEALTH RISK ASSESSMENT

SITE VICINITY MAP

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FIGURE 1-1

CITY: SF DIV/GROUP: ENV/IM DB: K ERNST LD: G FRANCE PIC: PM: TM: TR:
Project (Project #) B0081981.0008.00004
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Project (Project #) B0081981.0008.00004
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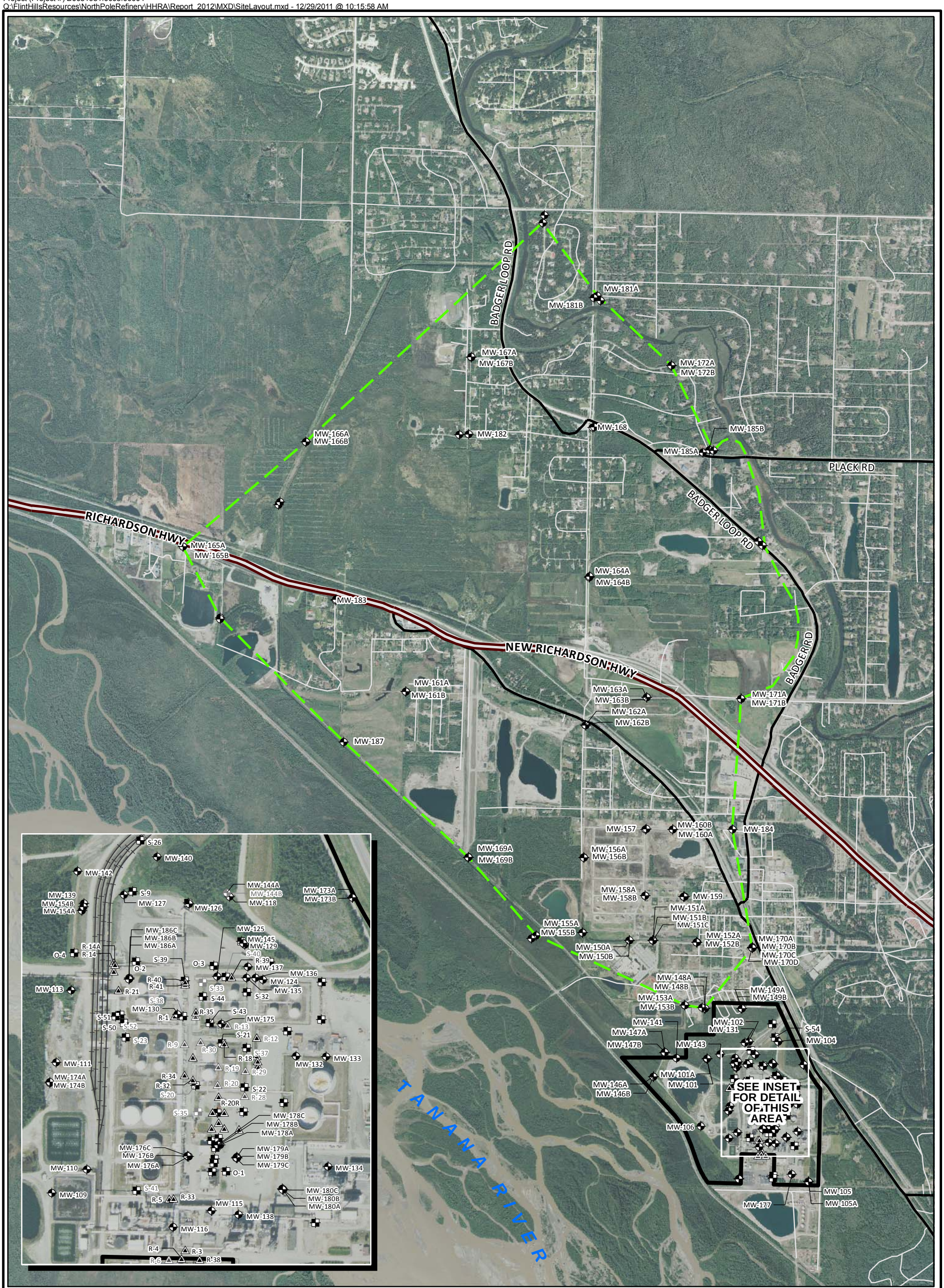

LEGEND

- MONITORING WELL
- OBSERVATION WELL
- RECOVERY WELL
- FHRA PROPERTY BOUNDARY- "ON-SITE"
- APPROXIMATE EXTENT OF "OFF-SITE" GROUNDWATER EXPOSURE UNIT
- HIGHWAY
- MAJOR ROAD
- LOCAL ROAD

Image Date June 9, 2007

0 2,000 4,000 Feet
GRAPHIC SCALE

FLINT HILLS RESOURCES ALASKA, LLC
NORTH POLE REFINERY, NORTH POLE, ALASKA

HUMAN HEALTH RISK ASSESSMENT

SITE LAYOUT

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FIGURE
2-1

CITY: KNX DIV/GROUP: ENV/GIS DB: PIC: PM: TM:
PROJECT: PATH:

HUMAN HEALTH CONCEPTUAL SITE MODEL GRAPHIC FORM

Site: FHR North Pole Refinery - On-Site Only

Completed By: R. Andresen

Date Completed: updated May 21, 2012

***Instructions*: Follow the numbered directions below. Do not consider contaminant concentrations or engineering/land use controls when describing pathways.**

(1) *Check the media that could be directly affected by the release.*

(2) *For each medium identified in (1), follow the top arrow and check possible transport mechanisms. Check additional media under (1) if the media acts as a secondary source.*

Media	Transport Mechanisms	check
☑ Surface Soil (0-2 ft bgs)	Direct release to surface soil	check soil
	☑ Migration to subsurface	check soil
	☑ Migration to groundwater	check groundwater
	☑ Volatilization	check air
	☑ Runoff or erosion	check surface water
	☐ Uptake by plants or animals	check biota
	☐ Other (list):	
☑ Subsurface Soil (2-15 ft bgs)	Direct release to subsurface soil	check soil
	☑ Migration to groundwater	check groundwater
	☑ Volatilization	check air
	☐ Uptake by plants or animals	check biota
	☐ Other (list):	
☑ Ground-water	Direct release to groundwater	check groundwater
	☑ Volatilization	check air
	☑ Flow to surface water body	check surface water
	☑ Flow to sediment	check sediment
	☑ Uptake by plants or animals	check biota
	☐ Other (list):	
☑ Surface Water	Direct release to surface water	check surface water
	☑ Volatilization	check air
	☑ Sedimentation	check sediment
	☑ Uptake by plants or animals	check biota
	☐ Other (list):	
☐ Sediment	Direct release to sediment	check sediment
	☐ Resuspension, runoff, or erosion	check surface water
	☐ Uptake by plants or animals	check biota
	☐ Other (list):	

(3) *Check all exposure media identified in (2).*

(4) *Check all pathways that could be complete. The pathways identified in this column **must** agree with Sections 2 and 3 of the Human Health CSM Scoping Form.*

(5) *Identify the receptors potentially affected by each exposure pathway: Enter "C" for current receptors, "F" for future receptors, "C/F" for both current and future receptors, or "I" for insignificant exposure.*

Current & Future Receptors

Exposure Media	Exposure Pathway/Route	Residents (adults or children)	Commercial or industrial workers	Site visitors, trespassers, or recreational users	Construction workers	Farmers or subsistence harvesters	Subsistence consumers	Other
☑ soil	☑ Incidental Soil Ingestion		C/F	I	C/F			
	☑ Dermal Absorption of Contaminants from Soil		C/F	I	C/F			
	☑ Inhalation of Fugitive Dust		C/F	I	C/F			
☑ groundwater	☑ Ingestion of Groundwater				I			
	☑ Dermal Absorption of Contaminants in Groundwater		I		C/F			
	☐ Inhalation of Volatile Compounds in Tap Water							
☑ air	☑ Inhalation of Outdoor Air		C/F	I	C/F			
	☑ Inhalation of Indoor Air		C/F	C/F				
	☑ Inhalation of Fugitive Dust		C/F	I	C/F			
☑ surface water	☐ Ingestion of Surface Water							
	☐ Dermal Absorption of Contaminants in Surface Water							
	☐ Inhalation of Volatile Compounds in Tap Water							
☑ sediment	☐ Direct Contact with Sediment							
☑ biota	☐ Ingestion of Wild or Farmed Foods							

FLINT HILLS RESOURCES ALASKA, LLC
NORTH POLE REFINERY, NORTH POLE, ALASKA
HUMAN HEALTH RISK ASSESSMENT

HUMAN HEALTH CONCEPTUAL SITE MODEL GRAPHIC FORM - ON SITE ONLY

ARCADIS

FIGURE 3-1

CITY: KNX DIV/GROUP: ENV/GIS DB: PIC: PM: TM:
PROJECT: PATH:

HUMAN HEALTH CONCEPTUAL SITE MODEL GRAPHIC FORM

Site: FHR North Pole Refinery - Off-Site Only

Completed By: R. Andresen

Date Completed: updated May 9, 2012

***Instructions*: Follow the numbered directions below. Do not consider contaminant concentrations or engineering/land use controls when describing pathways.**

(1) *Check the media that could be directly affected by the release.*

(2) *For each medium identified in (1), follow the top arrow and check possible transport mechanisms. Check additional media under (1) if the media acts as a secondary source.*

Media	Transport Mechanisms	check
☐ Surface Soil (0-2 ft bgs)	Direct release to surface soil	check soil
	☐ Migration to subsurface	check soil
	☐ Migration to groundwater	check groundwater
	☐ Volatilization	check air
	☐ Runoff or erosion	check surface water
	☐ Uptake by plants or animals	check biota
	☐ Other (list):	
☐ Subsurface Soil (2-15 ft bgs)	Direct release to subsurface soil	check soil
	☐ Migration to groundwater	check groundwater
	☐ Volatilization	check air
	☐ Uptake by plants or animals	check biota
	☐ Other (list):	
☑ Ground-water	Direct release to groundwater	check groundwater
	☐ Volatilization	check air
	☑ Flow to surface water body	check surface water
	☑ Flow to sediment	check sediment
	☑ Uptake by plants or animals	check biota
	☐ Other (list):	
☐ Surface Water	Direct release to surface water	check surface water
	☐ Volatilization	check air
	☐ Sedimentation	check sediment
	☐ Uptake by plants or animals	check biota
	☐ Other (list):	
☐ Sediment	Direct release to sediment	check sediment
	☐ Resuspension, runoff, or erosion	check surface water
	☐ Uptake by plants or animals	check biota
	☐ Other (list):	

(3) *Check all exposure media identified in (2).*

(4) *Check all pathways that could be complete. The pathways identified in this column **must** agree with Sections 2 and 3 of the Human Health CSM Scoping Form.*

(5) *Identify the receptors potentially affected by each exposure pathway: Enter "C" for current receptors, "F" for future receptors, "C/F" for both current and future receptors, or "I" for insignificant exposure.*

Current & Future Receptors

Exposure Media	Exposure Pathway/Route	Residents (adults or children)	Commercial or industrial workers	Site visitors, trespassers, or recreational users	Construction workers	Farmers or subsistence harvesters	Subsistence consumers	Other
☐ soil	☐ Incidental Soil Ingestion							
	☐ Dermal Absorption of Contaminants from Soil							
	☐ Inhalation of Fugitive Dust							
☑ groundwater	☑ Ingestion of Groundwater	C/F	C/F	C/F	C/F			
	☐ Dermal Absorption of Contaminants in Groundwater							
	☐ Inhalation of Volatile Compounds in Tap Water							
☑ air	☐ Inhalation of Outdoor Air							
	☐ Inhalation of Indoor Air							
	☑ Inhalation of Fugitive Dust	C/F	C/F					
☑ surface water	☑ Ingestion of Surface Water	C/F		C/F				
	☐ Dermal Absorption of Contaminants in Surface Water							
	☐ Inhalation of Volatile Compounds in Tap Water							
☑ sediment	☐ Direct Contact with Sediment							
☑ biota	☑ Ingestion of Wild or Farmed Foods	C/F		I				

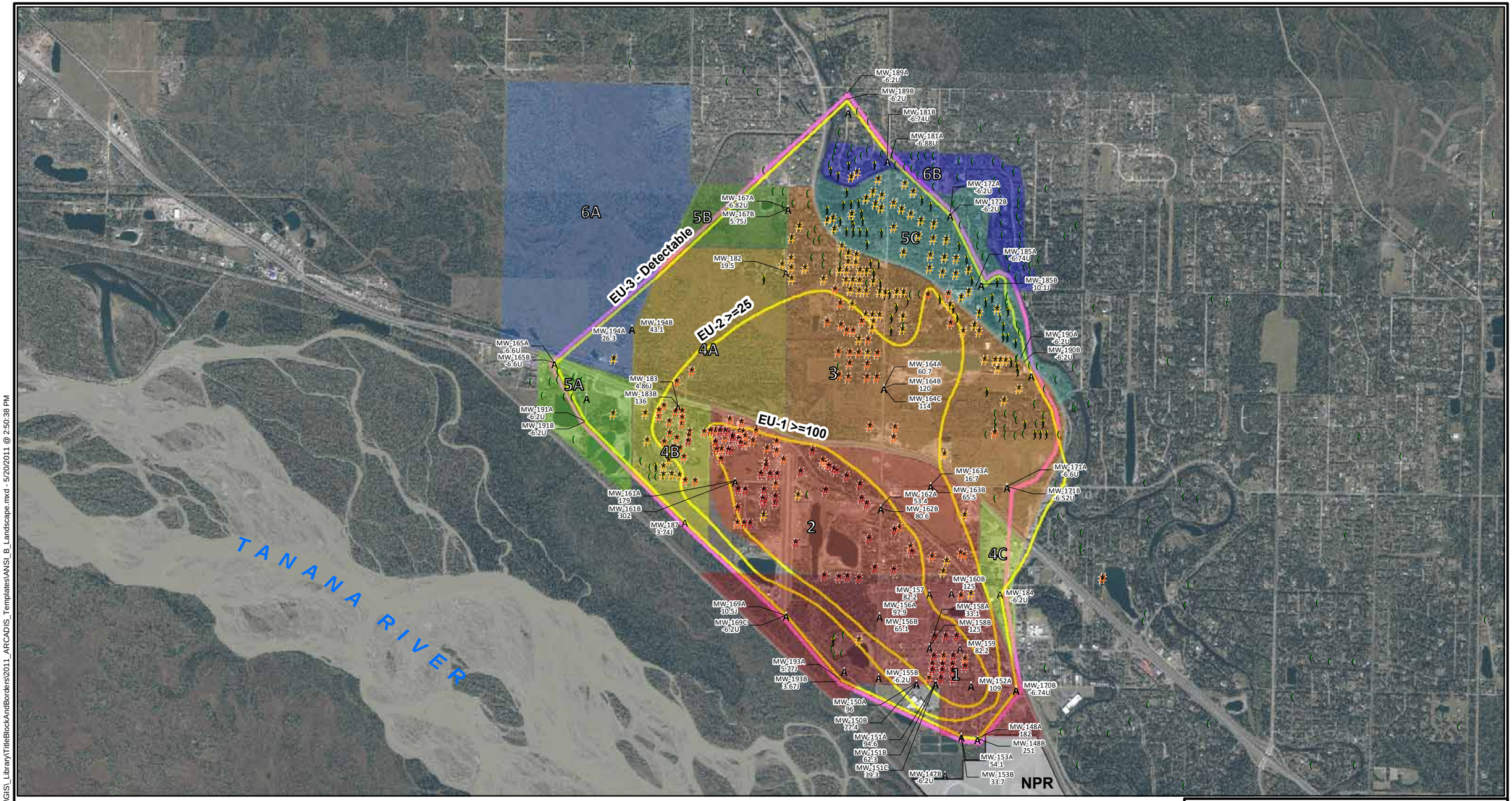
FLINT HILLS RESOURCES ALASKA, LLC
NORTH POLE REFINERY, NORTH POLE, ALASKA

HUMAN HEALTH RISK ASSESSMENT

HUMAN HEALTH CONCEPTUAL SITE MODEL GRAPHIC FORM - OFF SITE ONLY

ARCADIS

FIGURE 3-2



LEGEND

- # GREATER THAN 100 µG/L
- # 25 - 100 µG/L
- # 10 - 25 µG/L (CONTAINS J FLAGS)
-) 3.2 - 10 µG/L (J FLAGGED)
- (ND

SULFOLANE CONTOURS

APPROXIMATE EXTENT OF "OFF-SITE" GROUNDWATER EXPOSURE UNIT

0 2,500 5,000

SCALE IN FEET

FLINT HILLS RESOURCES ALASKA, LLC
NORTH POLE REFINERY, NORTH POLE, ALASKA
HUMAN HEALTH RISK ASSESSMENT

OFF-SITE GROUNDWATER EXPOSURE UNIT EVALUATION AREA

ARCADIS

FIGURE
3-3

CITY: SF DIV/GROUP: ENV/IM DB: K ERNST LD: G FRANCE PIC: PM: TM: TR:
Project (Project #) B0081981.0008.00004 G:\GIS_Library\TitleBlockAndBorders\2011_ARCADIS_Templates\ANSI_B_Landscape.mxd - 5/20/2011 @ 2:50:38 PM

ARCADIS

Appendix A

See CD for Electronic Tables

ARCADIS

Appendix B

USEPA ProUCL Outputs

See CD for Electronic Tables

Appendix B
Off-Site Groundwater by Exposure Units - ProUCL Output

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

General UCL Statistics for Data Sets with Non-Detects

User Selected Options

From File	WorkSheet.wst
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Sulfolane (>100 ppb)

General Statistics

Number of Valid Observations	105	Number of Distinct Observations	91

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.00505	Minimum of Log Data	-5.288
Maximum	0.443	Maximum of Log Data	-0.814
Mean	0.138	Mean of log Data	-2.127
Median	0.121	SD of log Data	0.606
SD	0.0736		
Std. Error of Mean	0.00719		
Coefficient of Variation	0.533		
Skewness	1.362		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.156	Lilliefors Test Statistic	0.117
Lilliefors Critical Value	0.0865	Lilliefors Critical Value	0.0865
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.15	95% H-UCL	0.16
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.183
95% Adjusted-CLT UCL (Chen-1995)	0.151	97.5% Chebyshev (MVUE) UCL	0.2
95% Modified-t UCL (Johnson-1978)	0.15	99% Chebyshev (MVUE) UCL	0.234

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	3.446	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0401		
MLE of Mean	0.138		
MLE of Standard Deviation	0.0745		
nu star	723.6		
Approximate Chi Square Value (.05)	662.2	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0477	95% CLT UCL	0.15
Adjusted Chi Square Value	661.4	95% Jackknife UCL	0.15
		95% Standard Bootstrap UCL	0.15
Anderson-Darling Test Statistic	1.286	95% Bootstrap-t UCL	0.152
Anderson-Darling 5% Critical Value	0.757	95% Hall's Bootstrap UCL	0.151
Kolmogorov-Smirnov Test Statistic	0.0941	95% Percentile Bootstrap UCL	0.15
Kolmogorov-Smirnov 5% Critical Value	0.0886	95% BCA Bootstrap UCL	0.151
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.17
		97.5% Chebyshev(Mean, Sd) UCL	0.183
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.21
95% Approximate Gamma UCL	0.151		
95% Adjusted Gamma UCL	0.151		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.17

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Sulfolane (>25 ppb)

General Statistics

Number of Valid Observations	73	Number of Distinct Observations	71

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.005	Minimum of Log Data	-5.298
Maximum	0.144	Maximum of Log Data	-1.938
Mean	0.0527	Mean of log Data	-3.113
Median	0.0468	SD of log Data	0.62
SD	0.0301		
Std. Error of Mean	0.00353		
Coefficient of Variation	0.572		
Skewness	1.075		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.116	Lilliefors Test Statistic	0.0505
Lilliefors Critical Value	0.104	Lilliefors Critical Value	0.104
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0585	95% H-UCL	0.0621
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0721
95% Adjusted-CLT UCL (Chen-1995)	0.0589	97.5% Chebyshev (MVUE) UCL	0.08
95% Modified-t UCL (Johnson-1978)	0.0586	99% Chebyshev (MVUE) UCL	0.0956

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	2.998	**Data appear Gamma Distributed at 5% Significance Level**	
Theta Star	0.0176		
MLE of Mean	0.0527		
MLE of Standard Deviation	0.0304		
nu star	437.7		
Approximate Chi Square Value (.05)	390.2	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0467	95% CLT UCL	0.0585
Adjusted Chi Square Value	389.3	95% Jackknife UCL	0.0585
		95% Standard Bootstrap UCL	0.0584
Anderson-Darling Test Statistic	0.179	95% Bootstrap-t UCL	0.0592
Anderson-Darling 5% Critical Value	0.758	95% Hall's Bootstrap UCL	0.0595
Kolmogorov-Smirnov Test Statistic	0.0449	95% Percentile Bootstrap UCL	0.0587
Kolmogorov-Smirnov 5% Critical Value	0.105	95% BCA Bootstrap UCL	0.059
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.068
		97.5% Chebyshev(Mean, Sd) UCL	0.0747
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0878
95% Approximate Gamma UCL	0.0591		
95% Adjusted Gamma UCL	0.0592		

Potential UCL to Use	
Use 95% Approximate Gamma UCL	0.0591

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Sulfolane (>detect)

General Statistics

Number of Valid Observations	294	Number of Distinct Observations	172

Raw Statistics		Log-transformed Statistics	
Minimum	0.0031	Minimum of Log Data	-5.776
Maximum	0.0802	Maximum of Log Data	-2.523
Mean	0.00855	Mean of log Data	-4.92
Median	0.00588	SD of log Data	0.516
SD	0.00651		
Std. Error of Mean	0.0003798		
Coefficient of Variation	0.761		
Skewness	5.269		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.213	Lilliefors Test Statistic	0.183
Lilliefors Critical Value	0.0517	Lilliefors Critical Value	0.0517
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.00918	95% H-UCL	0.0088
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00949
95% Adjusted-CLT UCL (Chen-1995)	0.0093	97.5% Chebyshev (MVUE) UCL	0.00999
95% Modified-t UCL (Johnson-1978)	0.0092	99% Chebyshev (MVUE) UCL	0.011

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	3.278	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.00261		
MLE of Mean	0.00855		
MLE of Standard Deviation	0.00472		
nu star	1928		
Approximate Chi Square Value (.05)	1827	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0492	95% CLT UCL	0.00918
Adjusted Chi Square Value	1826	95% Jackknife UCL	0.00918
		95% Standard Bootstrap UCL	0.00918
Anderson-Darling Test Statistic	17.1	95% Bootstrap-t UCL	0.00935
Anderson-Darling 5% Critical Value	0.759	95% Hall's Bootstrap UCL	0.00949
Kolmogorov-Smirnov Test Statistic	0.19	95% Percentile Bootstrap UCL	0.00918
Kolmogorov-Smirnov 5% Critical Value	0.0531	95% BCA Bootstrap UCL	0.00934
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0102
		97.5% Chebyshev(Mean, Sd) UCL	0.0109
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0123
95% Approximate Gamma UCL	0.00903		
95% Adjusted Gamma UCL	0.00903		

Potential UCL to Use			
		Use 95% Chebyshev (Mean, Sd) UCL	0.0102

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Appendix B
On-Site Groundwater - ProUCL Output

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

General UCL Statistics for Data Sets with Non-Detects

User Selected Options

From File	data.wst
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Result (1/2 DL for NDs) (1,1-dichloroethylene)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	2

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.000212	Minimum of Log Data	-8.459
Maximum	0.00031	Maximum of Log Data	-8.079
Mean	0.0002512	Mean of log Data	-8.307
Median	0.000212	SD of log Data	0.196
SD	5.061E-05		
Std. Error of Mean	1.6E-05		
Coefficient of Variation	0.201		
Skewness	0.484		

Warning: There are only 2 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.64	Shapiro Wilk Test Statistic	0.64
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0002805	95% H-UCL	0.0002845
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0003192
95% Adjusted-CLT UCL (Chen-1995)	0.0002801	97.5% Chebyshev (MVUE) UCL	0.0003487
95% Modified-t UCL (Johnson-1978)	0.0002809	99% Chebyshev (MVUE) UCL	0.0004066

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	19.99	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	1.257E-05		
MLE of Mean	0.0002512		
MLE of Standard Deviation	5.618E-05		
nu star	399.8		
Approximate Chi Square Value (.05)	354.5	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.0002775
Adjusted Chi Square Value	347.1	95% Jackknife UCL	N/A
		95% Standard Bootstrap UCL	N/A
Anderson-Darling Test Statistic	1.893	95% Bootstrap-t UCL	N/A
Anderson-Darling 5% Critical Value	0.725	95% Hall's Bootstrap UCL	N/A
Kolmogorov-Smirnov Test Statistic	0.393	95% Percentile Bootstrap UCL	N/A
Kolmogorov-Smirnov 5% Critical Value	0.266	95% BCA Bootstrap UCL	N/A
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.000321
		97.5% Chebyshev(Mean, Sd) UCL	0.0003511
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0004104
95% Approximate Gamma UCL	0.0002833		
95% Adjusted Gamma UCL	0.0002894		

Potential UCL to Use	
Use 95% Student's-t UCL	0.0002805
or 95% Modified-t UCL	0.0002809

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (1,2,4-trimethylbenzene)

General Statistics

Number of Valid Observations	30	Number of Distinct Observations	10

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0000961	Minimum of Log Data	-9.25
Maximum	0.472	Maximum of Log Data	-0.751
Mean	0.0339	Mean of log Data	-6.834
Median	0.0005	SD of log Data	2.455
SD	0.0991		
Std. Error of Mean	0.0181		
Coefficient of Variation	2.92		
Skewness	3.615		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.404	Shapiro Wilk Test Statistic	0.75
Shapiro Wilk Critical Value	0.927	Shapiro Wilk Critical Value	0.927
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0647	95% H-UCL	0.185
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0585
95% Adjusted-CLT UCL (Chen-1995)	0.0764	97.5% Chebyshev (MVUE) UCL	0.0769
95% Modified-t UCL (Johnson-1978)	0.0667	99% Chebyshev (MVUE) UCL	0.113
Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.213	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.16		
MLE of Mean	0.0339		
MLE of Standard Deviation	0.0736		
nu star	12.75		
Approximate Chi Square Value (.05)	5.726	**Nonparametric Statistics**	
Adjusted Level of Significance	0.041	95% CLT UCL	0.0637
Adjusted Chi Square Value	5.456	95% Jackknife UCL	0.0647
		95% Standard Bootstrap UCL	0.0632
Anderson-Darling Test Statistic	5.305	95% Bootstrap-t UCL	0.109
Anderson-Darling 5% Critical Value	0.893	95% Hall's Bootstrap UCL	0.0759
Kolmogorov-Smirnov Test Statistic	0.444	95% Percentile Bootstrap UCL	0.0692
Kolmogorov-Smirnov 5% Critical Value	0.177	95% BCA Bootstrap UCL	0.08
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.113
		97.5% Chebyshev(Mean, Sd) UCL	0.147
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.214
95% Approximate Gamma UCL	0.0756		
95% Adjusted Gamma UCL	0.0793		
Potential UCL to Use		Use 97.5% Chebyshev (Mean, Sd) UCL	0.147

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (1,3,5-trimethylbenzene)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	5

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.000113	Minimum of Log Data	-9.088
Maximum	0.121	Maximum of Log Data	-2.112
Mean	0.0213	Mean of log Data	-6.914
Median	0.000113	SD of log Data	2.968
SD	0.0412		
Std. Error of Mean	0.013		
Coefficient of Variation	1.935		
Skewness	2.062		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.61	Shapiro Wilk Test Statistic	0.73
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0452	95% H-UCL	179.8
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.107
95% Adjusted-CLT UCL (Chen-1995)	0.0518	97.5% Chebyshev (MVUE) UCL	0.143
95% Modified-t UCL (Johnson-1978)	0.0466	99% Chebyshev (MVUE) UCL	0.214

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.231	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0923		
MLE of Mean	0.0213		
MLE of Standard Deviation	0.0443		
nu star	4.613		
Approximate Chi Square Value (.05)	0.978	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.0427
Adjusted Chi Square Value	0.724	95% Jackknife UCL	0.0452
		95% Standard Bootstrap UCL	0.0416
Anderson-Darling Test Statistic	1.303	95% Bootstrap-t UCL	0.151
Anderson-Darling 5% Critical Value	0.84	95% Hall's Bootstrap UCL	0.196
Kolmogorov-Smirnov Test Statistic	0.371	95% Percentile Bootstrap UCL	0.0438
Kolmogorov-Smirnov 5% Critical Value	0.292	95% BCA Bootstrap UCL	0.0509
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0781
		97.5% Chebyshev(Mean, Sd) UCL	0.103
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.151
95% Approximate Gamma UCL	0.1		
95% Adjusted Gamma UCL	0.136		

Potential UCL to Use		
	Use 99% Chebyshev (Mean, Sd) UCL	0.151

Recommended UCL exceeds the maximum observation

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (1-methylnaphthalene)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	9

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.000015	Minimum of Log Data	-11.11
Maximum	0.035	Maximum of Log Data	-3.352
Mean	0.00557	Mean of log Data	-8.314
Median	6.025E-05	SD of log Data	3.209
SD	0.011		
Std. Error of Mean	0.00348		
Coefficient of Variation	1.976		
Skewness	2.562		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.592	Shapiro Wilk Test Statistic	0.796
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0119	95% H-UCL	332.5
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0417
95% Adjusted-CLT UCL (Chen-1995)	0.0143	97.5% Chebyshev (MVUE) UCL	0.056
95% Modified-t UCL (Johnson-1978)	0.0124	99% Chebyshev (MVUE) UCL	0.0841

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	0.228	**Data Follow Appr. Gamma Distribution at 5% Significance Level**
Theta Star	0.0244	
MLE of Mean	0.00557	
MLE of Standard Deviation	0.0117	
nu star	4.56	
Approximate Chi Square Value (.05)	0.954	**Nonparametric Statistics**
Adjusted Level of Significance	0.0267	95% CLT UCL 0.0113
Adjusted Chi Square Value	0.705	95% Jackknife UCL 0.0119
		95% Standard Bootstrap UCL 0.0109
Anderson-Darling Test Statistic	0.96	95% Bootstrap-t UCL 0.0236
Anderson-Darling 5% Critical Value	0.842	95% Hall's Bootstrap UCL 0.0284
Kolmogorov-Smirnov Test Statistic	0.292	95% Percentile Bootstrap UCL 0.0114
Kolmogorov-Smirnov 5% Critical Value	0.292	95% BCA Bootstrap UCL 0.0142
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0207
		97.5% Chebyshev(Mean, Sd) UCL 0.0273
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0402
95% Approximate Gamma UCL	0.0266	
95% Adjusted Gamma UCL	0.036	

Potential UCL to Use Use 95% Adjusted Gamma UCL 0.036

Recommended UCL exceeds the maximum observation

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2-methylnaphthalene)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	10

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0000156	Minimum of Log Data	-11.07
Maximum	0.0309	Maximum of Log Data	-3.477
Mean	0.00504	Mean of log Data	-8.263
Median	7.225E-05	SD of log Data	3.115
SD	0.00973		
Std. Error of Mean	0.00308		
Coefficient of Variation	1.931		
Skewness	2.503		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.603	Shapiro Wilk Test Statistic	0.811
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0107	95% H-UCL	155.9
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0366
95% Adjusted-CLT UCL (Chen-1995)	0.0127	97.5% Chebyshev (MVUE) UCL	0.0491
95% Modified-t UCL (Johnson-1978)	0.0111	99% Chebyshev (MVUE) UCL	0.0737

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.235	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0214		
MLE of Mean	0.00504		
MLE of Standard Deviation	0.0104		
nu star	4.7		
Approximate Chi Square Value (.05)	1.016	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.0101
Adjusted Chi Square Value	0.755	95% Jackknife UCL	0.0107
		95% Standard Bootstrap UCL	0.00971
Anderson-Darling Test Statistic	0.908	95% Bootstrap-t UCL	0.0201
Anderson-Darling 5% Critical Value	0.838	95% Hall's Bootstrap UCL	0.0252
Kolmogorov-Smirnov Test Statistic	0.292	95% Percentile Bootstrap UCL	0.0102
Kolmogorov-Smirnov 5% Critical Value	0.292	95% BCA Bootstrap UCL	0.0128
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0185
		97.5% Chebyshev(Mean, Sd) UCL	0.0243
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0357
95% Approximate Gamma UCL	0.0233		
95% Adjusted Gamma UCL	0.0314		

Potential UCL to Use	
Use 95% Hall's Bootstrap UCL	0.0252

In Case Bootstrap t and/or Hall's Bootstrap yields an unreasonably large UCL value, use 97.5% or 99% Chebyshev (Mean, Sd) UCL

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (4-isopropyltoluene (p-cymene))

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	5

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0000769	Minimum of Log Data	-9.473
Maximum	0.0334	Maximum of Log Data	-3.399
Mean	0.00428	Mean of log Data	-7.868
Median	0.0000769	SD of log Data	2.286
SD	0.0104		
Std. Error of Mean	0.00328		
Coefficient of Variation	2.422		
Skewness	3.013		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.475	Shapiro Wilk Test Statistic	0.741
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0103	95% H-UCL	0.542
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0117
95% Adjusted-CLT UCL (Chen-1995)	0.013	97.5% Chebyshev (MVUE) UCL	0.0156
95% Modified-t UCL (Johnson-1978)	0.0108	99% Chebyshev (MVUE) UCL	0.0232

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.268	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.016		
MLE of Mean	0.00428		
MLE of Standard Deviation	0.00827		
nu star	5.359		
Approximate Chi Square Value (.05)	1.322	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.00968
Adjusted Chi Square Value	1.008	95% Jackknife UCL	0.0103
		95% Standard Bootstrap UCL	0.0094
Anderson-Darling Test Statistic	1.42	95% Bootstrap-t UCL	0.0357
Anderson-Darling 5% Critical Value	0.819	95% Hall's Bootstrap UCL	0.0362
Kolmogorov-Smirnov Test Statistic	0.356	95% Percentile Bootstrap UCL	0.0106
Kolmogorov-Smirnov 5% Critical Value	0.289	95% BCA Bootstrap UCL	0.0138
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0186
		97.5% Chebyshev(Mean, Sd) UCL	0.0248
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0369
95% Approximate Gamma UCL	0.0174		
95% Adjusted Gamma UCL	0.0228		

Potential UCL to Use		
		Use 99% Chebyshev (Mean, Sd) UCL 0.0369

Recommended UCL exceeds the maximum observation

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (acenaphthene)

General Statistics

Number of Valid Observations 2 Number of Distinct Observations 1

Warning: This data set only has 2 observations!
Data set is too small to compute reliable and meaningful statistics and estimates!
The data set for variable Result (1/2 DL for NDs) (acenaphthene) was not processed!

It is suggested to collect at least 8 to 10 observations before using these statistical methods!
If possible, compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Result (1/2 DL for NDs) (acenaphthylene)

General Statistics

Number of Valid Observations 2 Number of Distinct Observations 1

Warning: This data set only has 2 observations!
Data set is too small to compute reliable and meaningful statistics and estimates!
The data set for variable Result (1/2 DL for NDs) (acenaphthylene) was not processed!

It is suggested to collect at least 8 to 10 observations before using these statistical methods!
If possible, compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Result (1/2 DL for NDs) (alkalinity)

General Statistics

Number of Valid Observations	6	Number of Distinct Observations	5

Raw Statistics		**Log-transformed Statistics**	
Minimum	147	Minimum of Log Data	4.99
Maximum	185	Maximum of Log Data	5.22
Mean	162.3	Mean of log Data	5.087
Median	164.5	SD of log Data	0.0867
SD	14.19		
Std. Error of Mean	5.795		
Coefficient of Variation	0.0874		
Skewness	0.473		

Warning: A sample size of 'n' = 6 may not adequate enough to compute meaningful and reliable test statistics and estimates!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Warning: There are only 6 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set,
the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.885	Shapiro Wilk Test Statistic	0.886
Shapiro Wilk Critical Value	0.788	Shapiro Wilk Critical Value	0.788
Data appear Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	174	95% H-UCL	N/A
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	187.4
95% Adjusted-CLT UCL (Chen-1995)	173.1	97.5% Chebyshev (MVUE) UCL	198.2
95% Modified-t UCL (Johnson-1978)	174.2	99% Chebyshev (MVUE) UCL	219.5

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	79.6	**Data appear Normal at 5% Significance Level**	
Theta Star	2.039		
MLE of Mean	162.3		
MLE of Standard Deviation	18.19		
nu star	955.2		
Approximate Chi Square Value (.05)	884.5	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0122	95% CLT UCL	171.9
Adjusted Chi Square Value	859.6	95% Jackknife UCL	174
		95% Standard Bootstrap UCL	170.9
Anderson-Darling Test Statistic	0.456	95% Bootstrap-t UCL	175.9
Anderson-Darling 5% Critical Value	0.696	95% Hall's Bootstrap UCL	173.3
Kolmogorov-Smirnov Test Statistic	0.228	95% Percentile Bootstrap UCL	171.8
Kolmogorov-Smirnov 5% Critical Value	0.332	95% BCA Bootstrap UCL	171.5
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	187.6
		97.5% Chebyshev(Mean, Sd) UCL	198.5
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	220
95% Approximate Gamma UCL	175.3		
95% Adjusted Gamma UCL	180.4		

Potential UCL to Use	
Use 95% Student's-t UCL	174

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (anthracene)

General Statistics

Number of Valid Observations 2 Number of Distinct Observations 1

Warning: This data set only has 2 observations!
Data set is too small to compute reliable and meaningful statistics and estimates!
The data set for variable Result (1/2 DL for NDs) (anthracene) was not processed!

It is suggested to collect at least 8 to 10 observations before using these statistical methods!
If possible, compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Result (1/2 DL for NDs) (antimony)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	2

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.00031	Minimum of Log Data	-8.079
Maximum	0.00035	Maximum of Log Data	-7.958
Mean	0.000314	Mean of log Data	-8.067
Median	0.00031	SD of log Data	0.0384
SD	1.265E-05		
Std. Error of Mean	0.000004		
Coefficient of Variation	0.0403		
Skewness	3.162		

Warning: There are only 2 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.366	Shapiro Wilk Test Statistic	0.366
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0003213	95% H-UCL	N/A
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0003306
95% Adjusted-CLT UCL (Chen-1995)	0.0003249	97.5% Chebyshev (MVUE) UCL	0.0003378
95% Modified-t UCL (Johnson-1978)	0.000322	99% Chebyshev (MVUE) UCL	0.0003519

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	511.4	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	6.14E-07		
MLE of Mean	0.000314		
MLE of Standard Deviation	1.389E-05		
nu star	10229		
Approximate Chi Square Value (.05)	9994	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.0003206
Adjusted Chi Square Value	9954	95% Jackknife UCL	N/A
		95% Standard Bootstrap UCL	N/A
Anderson-Darling Test Statistic	3.295	95% Bootstrap-t UCL	N/A
Anderson-Darling 5% Critical Value	0.724	95% Hall's Bootstrap UCL	N/A
Kolmogorov-Smirnov Test Statistic	0.531	95% Percentile Bootstrap UCL	N/A
Kolmogorov-Smirnov 5% Critical Value	0.266	95% BCA Bootstrap UCL	N/A
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0003314
		97.5% Chebyshev(Mean, Sd) UCL	0.000339
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0003538
95% Approximate Gamma UCL	0.0003214		
95% Adjusted Gamma UCL	0.0003227		

Potential UCL to Use	
Use 95% Student's-t UCL	0.0003213
or 95% Modified-t UCL	0.000322

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (bap teq)

General Statistics

Number of Valid Observations	11	Number of Distinct Observations	4

Raw Statistics		Log-transformed Statistics	
Minimum	3.465E-05	Minimum of Log Data	-10.27
Maximum	5.778E-05	Maximum of Log Data	-9.759
Mean	3.705E-05	Mean of log Data	-10.22
Median	3.465E-05	SD of log Data	0.153
SD	6.906E-06		
Std. Error of Mean	2.082E-06		
Coefficient of Variation	N/A		
Skewness	3.264		

Warning: There are only 4 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.404	Shapiro Wilk Test Statistic	0.42
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	4.082E-05	95% H-UCL	4.043E-05
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	4.442E-05
95% Adjusted-CLT UCL (Chen-1995)	4.266E-05	97.5% Chebyshev (MVUE) UCL	4.764E-05
95% Modified-t UCL (Johnson-1978)	4.116E-05	99% Chebyshev (MVUE) UCL	5.395E-05

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	30.23	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	1.226E-06		
MLE of Mean	3.705E-05		
MLE of Standard Deviation	6.738E-06		
nu star	665		
Approximate Chi Square Value (.05)	606.2	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0278	95% CLT UCL	4.047E-05
Adjusted Chi Square Value	597	95% Jackknife UCL	4.082E-05
		95% Standard Bootstrap UCL	4.035E-05
Anderson-Darling Test Statistic	3.08	95% Bootstrap-t UCL	6.466E-05
Anderson-Darling 5% Critical Value	0.728	95% Hall's Bootstrap UCL	6.499E-05
Kolmogorov-Smirnov Test Statistic	0.427	95% Percentile Bootstrap UCL	4.113E-05
Kolmogorov-Smirnov 5% Critical Value	0.255	95% BCA Bootstrap UCL	4.323E-05
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	4.612E-05
		97.5% Chebyshev(Mean, Sd) UCL	5.005E-05
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	5.776E-05
95% Approximate Gamma UCL	4.064E-05		
95% Adjusted Gamma UCL	4.127E-05		

Potential UCL to Use		
	Use 95% Student's-t UCL	4.082E-05
	or 95% Modified-t UCL	4.116E-05

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (barium)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	10

Raw Statistics		Log-transformed Statistics	
Minimum	0.0443	Minimum of Log Data	-3.117
Maximum	0.41	Maximum of Log Data	-0.892
Mean	0.192	Mean of log Data	-1.849
Median	0.168	SD of log Data	0.692
SD	0.122		
Std. Error of Mean	0.0387		
Coefficient of Variation	0.638		
Skewness	0.987		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.871	Shapiro Wilk Test Statistic	0.942
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data appear Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.262	95% H-UCL	0.357
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.385
95% Adjusted-CLT UCL (Chen-1995)	0.268	97.5% Chebyshev (MVUE) UCL	0.468
95% Modified-t UCL (Johnson-1978)	0.264	99% Chebyshev (MVUE) UCL	0.63

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	1.958	**Data appear Normal at 5% Significance Level**	
Theta Star	0.0978		
MLE of Mean	0.192		
MLE of Standard Deviation	0.137		
nu star	39.15		
Approximate Chi Square Value (.05)	25.82	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.255
Adjusted Chi Square Value	23.95	95% Jackknife UCL	0.262
		95% Standard Bootstrap UCL	0.252
Anderson-Darling Test Statistic	0.321	95% Bootstrap-t UCL	0.316
Anderson-Darling 5% Critical Value	0.733	95% Hall's Bootstrap UCL	0.707
Kolmogorov-Smirnov Test Statistic	0.17	95% Percentile Bootstrap UCL	0.255
Kolmogorov-Smirnov 5% Critical Value	0.269	95% BCA Bootstrap UCL	0.26
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.36
		97.5% Chebyshev(Mean, Sd) UCL	0.433
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.576
95% Approximate Gamma UCL	0.29		
95% Adjusted Gamma UCL	0.313		

Potential UCL to Use			
		Use 95% Student's-t UCL	0.262

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzo(a)anthracene)

General Statistics

Number of Valid Observations	11	Number of Distinct Observations	4

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.000015	Minimum of Log Data	-11.11
Maximum	0.000025	Maximum of Log Data	-10.6
Mean	1.604E-05	Mean of log Data	-11.05
Median	0.000015	SD of log Data	0.152
SD	2.986E-06		
Std. Error of Mean	9.004E-07		
Coefficient of Variation	N/A		
Skewness	3.264		

Warning: There are only 4 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.404	Shapiro Wilk Test Statistic	0.42
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	1.767E-05	95% H-UCL	1.75E-05
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.923E-05
95% Adjusted-CLT UCL (Chen-1995)	1.846E-05	97.5% Chebyshev (MVUE) UCL	2.062E-05
95% Modified-t UCL (Johnson-1978)	1.782E-05	99% Chebyshev (MVUE) UCL	2.335E-05
Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	30.28	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	5.296E-07		
MLE of Mean	1.604E-05		
MLE of Standard Deviation	2.914E-06		
nu star	666.2		
Approximate Chi Square Value (.05)	607.3	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0278	95% CLT UCL	1.752E-05
Adjusted Chi Square Value	598.1	95% Jackknife UCL	1.767E-05
		95% Standard Bootstrap UCL	1.742E-05
Anderson-Darling Test Statistic	3.079	95% Bootstrap-t UCL	2.797E-05
Anderson-Darling 5% Critical Value	0.728	95% Hall's Bootstrap UCL	2.811E-05
Kolmogorov-Smirnov Test Statistic	0.427	95% Percentile Bootstrap UCL	0.0000178
Kolmogorov-Smirnov 5% Critical Value	0.255	95% BCA Bootstrap UCL	1.864E-05
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1.996E-05
		97.5% Chebyshev(Mean, Sd) UCL	2.166E-05
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	2.5E-05
95% Approximate Gamma UCL	1.759E-05		
95% Adjusted Gamma UCL	1.786E-05		
Potential UCL to Use		Use 95% Student's-t UCL	1.767E-05
		or 95% Modified-t UCL	1.782E-05

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzo(a)pyrene)

General Statistics

Number of Valid Observations	11	Number of Distinct Observations	4

Raw Statistics		Log-transformed Statistics	
Minimum	0.000015	Minimum of Log Data	-11.11
Maximum	0.000025	Maximum of Log Data	-10.6
Mean	1.604E-05	Mean of log Data	-11.05
Median	0.000015	SD of log Data	0.152
SD	2.986E-06		
Std. Error of Mean	9.004E-07		
Coefficient of Variation	N/A		
Skewness	3.264		

Warning: There are only 4 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.404	Shapiro Wilk Test Statistic	0.42
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	1.767E-05	95% H-UCL	1.75E-05
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.923E-05
95% Adjusted-CLT UCL (Chen-1995)	1.846E-05	97.5% Chebyshev (MVUE) UCL	2.062E-05
95% Modified-t UCL (Johnson-1978)	1.782E-05	99% Chebyshev (MVUE) UCL	2.335E-05

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	30.28	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	5.296E-07		
MLE of Mean	1.604E-05		
MLE of Standard Deviation	2.914E-06		
nu star	666.2		
Approximate Chi Square Value (.05)	607.3	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0278	95% CLT UCL	1.752E-05
Adjusted Chi Square Value	598.1	95% Jackknife UCL	1.767E-05
		95% Standard Bootstrap UCL	1.743E-05
Anderson-Darling Test Statistic	3.079	95% Bootstrap-t UCL	2.797E-05
Anderson-Darling 5% Critical Value	0.728	95% Hall's Bootstrap UCL	2.811E-05
Kolmogorov-Smirnov Test Statistic	0.427	95% Percentile Bootstrap UCL	0.0000178
Kolmogorov-Smirnov 5% Critical Value	0.255	95% BCA Bootstrap UCL	1.798E-05
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1.996E-05
		97.5% Chebyshev(Mean, Sd) UCL	2.166E-05
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	2.5E-05
95% Approximate Gamma UCL	1.759E-05		
95% Adjusted Gamma UCL	1.786E-05		

Potential UCL to Use	
Use 95% Student's-t UCL	1.767E-05
or 95% Modified-t UCL	1.782E-05

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzo(b)fluoranthene)

General Statistics

Number of Valid Observations	11	Number of Distinct Observations	4

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.000015	Minimum of Log Data	-11.11
Maximum	0.000025	Maximum of Log Data	-10.6
Mean	1.604E-05	Mean of log Data	-11.05
Median	0.000015	SD of log Data	0.152
SD	2.986E-06		
Std. Error of Mean	9.004E-07		
Coefficient of Variation	N/A		
Skewness	3.264		

Warning: There are only 4 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.404	Shapiro Wilk Test Statistic	0.42
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	1.767E-05	95% H-UCL	1.75E-05
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.923E-05
95% Adjusted-CLT UCL (Chen-1995)	1.846E-05	97.5% Chebyshev (MVUE) UCL	2.062E-05
95% Modified-t UCL (Johnson-1978)	1.782E-05	99% Chebyshev (MVUE) UCL	2.335E-05
Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	30.28	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	5.296E-07		
MLE of Mean	1.604E-05		
MLE of Standard Deviation	2.914E-06		
nu star	666.2		
Approximate Chi Square Value (.05)	607.3	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0278	95% CLT UCL	1.752E-05
Adjusted Chi Square Value	598.1	95% Jackknife UCL	1.767E-05
		95% Standard Bootstrap UCL	1.743E-05
Anderson-Darling Test Statistic	3.079	95% Bootstrap-t UCL	2.797E-05
Anderson-Darling 5% Critical Value	0.728	95% Hall's Bootstrap UCL	2.811E-05
Kolmogorov-Smirnov Test Statistic	0.427	95% Percentile Bootstrap UCL	0.0000178
Kolmogorov-Smirnov 5% Critical Value	0.255	95% BCA Bootstrap UCL	1.804E-05
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1.996E-05
		97.5% Chebyshev(Mean, Sd) UCL	2.166E-05
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	2.5E-05
95% Approximate Gamma UCL	1.759E-05		
95% Adjusted Gamma UCL	1.786E-05		
Potential UCL to Use		Use 95% Student's-t UCL	1.767E-05
		or 95% Modified-t UCL	1.782E-05

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzo(g,h,i)perylene)

General Statistics

Number of Valid Observations 2 Number of Distinct Observations 1

Warning: This data set only has 2 observations!
Data set is too small to compute reliable and meaningful statistics and estimates!
The data set for variable Result (1/2 DL for NDs) (benzo(g,h,i)perylene) was not processed!

It is suggested to collect at least 8 to 10 observations before using these statistical methods!
If possible, compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Result (1/2 DL for NDs) (benzo(k)fluoranthene)

General Statistics

Number of Valid Observations	11	Number of Distinct Observations	4

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.000015	Minimum of Log Data	-11.11
Maximum	0.000025	Maximum of Log Data	-10.6
Mean	1.604E-05	Mean of log Data	-11.05
Median	0.000015	SD of log Data	0.152
SD	2.986E-06		
Std. Error of Mean	9.004E-07		
Coefficient of Variation	N/A		
Skewness	3.264		

Warning: There are only 4 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.404	Shapiro Wilk Test Statistic	0.42
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	1.767E-05	95% H-UCL	1.75E-05
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.923E-05
95% Adjusted-CLT UCL (Chen-1995)	1.846E-05	97.5% Chebyshev (MVUE) UCL	2.062E-05
95% Modified-t UCL (Johnson-1978)	1.782E-05	99% Chebyshev (MVUE) UCL	2.335E-05
Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	30.28	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	5.296E-07		
MLE of Mean	1.604E-05		
MLE of Standard Deviation	2.914E-06		
nu star	666.2		
Approximate Chi Square Value (.05)	607.3	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0278	95% CLT UCL	1.752E-05
Adjusted Chi Square Value	598.1	95% Jackknife UCL	1.767E-05
		95% Standard Bootstrap UCL	1.74E-05
Anderson-Darling Test Statistic	3.079	95% Bootstrap-t UCL	2.797E-05
Anderson-Darling 5% Critical Value	0.728	95% Hall's Bootstrap UCL	2.811E-05
Kolmogorov-Smirnov Test Statistic	0.427	95% Percentile Bootstrap UCL	0.0000178
Kolmogorov-Smirnov 5% Critical Value	0.255	95% BCA Bootstrap UCL	1.798E-05
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1.996E-05
		97.5% Chebyshev(Mean, Sd) UCL	2.166E-05
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	2.5E-05
95% Approximate Gamma UCL	1.759E-05		
95% Adjusted Gamma UCL	1.786E-05		
Potential UCL to Use		Use 95% Student's-t UCL	1.767E-05
		or 95% Modified-t UCL	1.782E-05

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (cadmium)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	1

Warning: There is only one distinct observation value in this data set - resulting in '0' variance!
ProUCL (or any other software) should not be used on such a data set!
The data set for variable Result (1/2 DL for NDs) (cadmium) was not processed!

If possible, compute and collect Data Quality Objectives (DQOs) based sample size and analytical results.
The Project Team may decide to use alternative site specific values to estimate environmental parameters (e.g., EPC, BTV).

Result (1/2 DL for NDs) (chromium (total))

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	5

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0012	Minimum of Log Data	-6.725
Maximum	0.0021	Maximum of Log Data	-6.166
Mean	0.00131	Mean of log Data	-6.654
Median	0.0012	SD of log Data	0.173
SD	0.0002796		
Std. Error of Mean	8.842E-05		
Coefficient of Variation	0.214		
Skewness	3.092		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.449	Shapiro Wilk Test Statistic	0.474
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.00147	95% H-UCL	0.00146
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00162
95% Adjusted-CLT UCL (Chen-1995)	0.00155	97.5% Chebyshev (MVUE) UCL	0.00175
95% Modified-t UCL (Johnson-1978)	0.00149	99% Chebyshev (MVUE) UCL	0.00202

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	22.67	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	5.775E-05		
MLE of Mean	0.00131		
MLE of Standard Deviation	0.0002749		
nu star	453.4		
Approximate Chi Square Value (.05)	405	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.00145
Adjusted Chi Square Value	397	95% Jackknife UCL	0.00147
		95% Standard Bootstrap UCL	0.00145
Anderson-Darling Test Statistic	2.518	95% Bootstrap-t UCL	0.0024
Anderson-Darling 5% Critical Value	0.724	95% Hall's Bootstrap UCL	0.00211
Kolmogorov-Smirnov Test Statistic	0.427	95% Percentile Bootstrap UCL	0.00148
Kolmogorov-Smirnov 5% Critical Value	0.266	95% BCA Bootstrap UCL	0.00157
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.00169
		97.5% Chebyshev(Mean, Sd) UCL	0.00186
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.00219
95% Approximate Gamma UCL	0.00147		
95% Adjusted Gamma UCL	0.00149		

Potential UCL to Use		
	Use 95% Student's-t UCL	0.00147
	or 95% Modified-t UCL	0.00149

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (chrysene)

General Statistics

Number of Valid Observations 2 Number of Distinct Observations 1

Warning: This data set only has 2 observations!
Data set is too small to compute reliable and meaningful statistics and estimates!
The data set for variable Result (1/2 DL for NDs) (chrysene) was not processed!

It is suggested to collect at least 8 to 10 observations before using these statistical methods!
If possible, compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Result (1/2 DL for NDs) (co3 alkalinity)

General Statistics

Number of Valid Observations 6 Number of Distinct Observations 1

Warning: There is only one distinct observation value in this data set - resulting in '0' variance!
ProUCL (or any other software) should not be used on such a data set!
The data set for variable Result (1/2 DL for NDs) (co3 alkalinity) was not processed!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible, compute and collect Data Quality Objectives (DQOs) based sample size and analytical results.
The Project Team may decide to use alternative site specific values to estimate environmental parameters (e.g., EPC, BTV).

Result (1/2 DL for NDs) (copper)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	7

Raw Statistics		Log-transformed Statistics	
Minimum	0.0018	Minimum of Log Data	-6.32
Maximum	0.00784	Maximum of Log Data	-4.849
Mean	0.00324	Mean of log Data	-5.864
Median	0.00257	SD of log Data	0.513
SD	0.00197		
Std. Error of Mean	0.0006245		
Coefficient of Variation	0.609		
Skewness	1.701		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.776	Shapiro Wilk Test Statistic	0.861
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.00439	95% H-UCL	0.00475
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0055
95% Adjusted-CLT UCL (Chen-1995)	0.00463	97.5% Chebyshev (MVUE) UCL	0.00649
95% Modified-t UCL (Johnson-1978)	0.00444	99% Chebyshev (MVUE) UCL	0.00845

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	2.827	**Data appear Gamma Distributed at 5% Significance Level**	
Theta Star	0.00115		
MLE of Mean	0.00324		
MLE of Standard Deviation	0.00193		
nu star	56.54		
Approximate Chi Square Value (.05)	40.26	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.00427
Adjusted Chi Square Value	37.88	95% Jackknife UCL	0.00439
		95% Standard Bootstrap UCL	0.00424
Anderson-Darling Test Statistic	0.681	95% Bootstrap-t UCL	0.00564
Anderson-Darling 5% Critical Value	0.73	95% Hall's Bootstrap UCL	0.00905
Kolmogorov-Smirnov Test Statistic	0.213	95% Percentile Bootstrap UCL	0.00435
Kolmogorov-Smirnov 5% Critical Value	0.268	95% BCA Bootstrap UCL	0.00468
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.00596
		97.5% Chebyshev(Mean, Sd) UCL	0.00714
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.00945
95% Approximate Gamma UCL	0.00455		
95% Adjusted Gamma UCL	0.00484		

Potential UCL to Use			
		Use 95% Approximate Gamma UCL	0.00455

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (cyanide)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	6

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0015	Minimum of Log Data	-6.502
Maximum	0.0046	Maximum of Log Data	-5.382
Mean	0.00205	Mean of log Data	-6.257
Median	0.0017	SD of log Data	0.353
SD	0.0009504		
Std. Error of Mean	0.0003006		
Coefficient of Variation	0.464		
Skewness	2.552		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.634	Shapiro Wilk Test Statistic	0.739
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0026	95% H-UCL	0.00259
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00302
95% Adjusted-CLT UCL (Chen-1995)	0.0028	97.5% Chebyshev (MVUE) UCL	0.00345
95% Modified-t UCL (Johnson-1978)	0.00264	99% Chebyshev (MVUE) UCL	0.0043

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	5.413	**Data Follow Appr. Gamma Distribution at 5% Significance Level**	
Theta Star	0.0003788		
MLE of Mean	0.00205		
MLE of Standard Deviation	0.0008812		
nu star	108.3		
Approximate Chi Square Value (.05)	85.24	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.00254
Adjusted Chi Square Value	81.69	95% Jackknife UCL	0.0026
		95% Standard Bootstrap UCL	0.00251
Anderson-Darling Test Statistic	1.173	95% Bootstrap-t UCL	0.00343
Anderson-Darling 5% Critical Value	0.727	95% Hall's Bootstrap UCL	0.00443
Kolmogorov-Smirnov Test Statistic	0.257	95% Percentile Bootstrap UCL	0.00258
Kolmogorov-Smirnov 5% Critical Value	0.267	95% BCA Bootstrap UCL	0.0028
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.00336
		97.5% Chebyshev(Mean, Sd) UCL	0.00393
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.00504
95% Approximate Gamma UCL	0.0026		
95% Adjusted Gamma UCL	0.00272		

Potential UCL to Use	
Use 95% Approximate Gamma UCL	0.0026

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (cyclohexane)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	5

Raw Statistics		Log-transformed Statistics	
Minimum	0.000163	Minimum of Log Data	-8.722
Maximum	0.498	Maximum of Log Data	-0.697
Mean	0.128	Mean of log Data	-5.843
Median	0.000163	SD of log Data	3.788
SD	0.204		
Std. Error of Mean	0.0646		
Coefficient of Variation	1.591		
Skewness	1.202		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.67	Shapiro Wilk Test Statistic	0.695
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.247	95% H-UCL	951246
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.542
95% Adjusted-CLT UCL (Chen-1995)	0.261	97.5% Chebyshev (MVUE) UCL	2.078
95% Modified-t UCL (Johnson-1978)	0.251	99% Chebyshev (MVUE) UCL	3.13

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.203	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.632		
MLE of Mean	0.128		
MLE of Standard Deviation	0.285		
nu star	4.063		
Approximate Chi Square Value (.05)	0.747	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.234
Adjusted Chi Square Value	0.538	95% Jackknife UCL	0.247
		95% Standard Bootstrap UCL	0.229
Anderson-Darling Test Statistic	1.404	95% Bootstrap-t UCL	0.32
Anderson-Darling 5% Critical Value	0.856	95% Hall's Bootstrap UCL	0.196
Kolmogorov-Smirnov Test Statistic	0.385	95% Percentile Bootstrap UCL	0.237
Kolmogorov-Smirnov 5% Critical Value	0.294	95% BCA Bootstrap UCL	0.261
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.41
		97.5% Chebyshev(Mean, Sd) UCL	0.531
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.771
95% Approximate Gamma UCL	0.698		
95% Adjusted Gamma UCL	0.968		

Potential UCL to Use		
		Use 95% Hall's Bootstrap UCL 0.196

In Case Bootstrap t and/or Hall's Bootstrap yields an unreasonably large UCL value, use 97.5% or 99% Chebyshev (Mean, Sd) UCL

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (dibenzo(a,h)anthracene)

General Statistics

Number of Valid Observations	11	Number of Distinct Observations	4

Raw Statistics		Log-transformed Statistics	
Minimum	0.000015	Minimum of Log Data	-11.11
Maximum	0.000025	Maximum of Log Data	-10.6
Mean	1.604E-05	Mean of log Data	-11.05
Median	0.000015	SD of log Data	0.152
SD	2.986E-06		
Std. Error of Mean	9.004E-07		
Coefficient of Variation	N/A		
Skewness	3.264		

Warning: There are only 4 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.404	Shapiro Wilk Test Statistic	0.42
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	1.767E-05	95% H-UCL	1.75E-05
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.923E-05
95% Adjusted-CLT UCL (Chen-1995)	1.846E-05	97.5% Chebyshev (MVUE) UCL	2.062E-05
95% Modified-t UCL (Johnson-1978)	1.782E-05	99% Chebyshev (MVUE) UCL	2.335E-05

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	30.28	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	5.296E-07		
MLE of Mean	1.604E-05		
MLE of Standard Deviation	2.914E-06		
nu star	666.2		
Approximate Chi Square Value (.05)	607.3	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0278	95% CLT UCL	1.752E-05
Adjusted Chi Square Value	598.1	95% Jackknife UCL	1.767E-05
		95% Standard Bootstrap UCL	1.748E-05
Anderson-Darling Test Statistic	3.079	95% Bootstrap-t UCL	2.797E-05
Anderson-Darling 5% Critical Value	0.728	95% Hall's Bootstrap UCL	2.811E-05
Kolmogorov-Smirnov Test Statistic	0.427	95% Percentile Bootstrap UCL	0.0000178
Kolmogorov-Smirnov 5% Critical Value	0.255	95% BCA Bootstrap UCL	1.864E-05
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1.996E-05
		97.5% Chebyshev(Mean, Sd) UCL	2.166E-05
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	2.5E-05
95% Approximate Gamma UCL	1.759E-05		
95% Adjusted Gamma UCL	1.786E-05		

Potential UCL to Use	
Use 95% Student's-t UCL	1.767E-05
or 95% Modified-t UCL	1.782E-05

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (dibenzofuran)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	2

Raw Statistics		Log-transformed Statistics	
Minimum	0.0031	Minimum of Log Data	-5.776
Maximum	0.0032	Maximum of Log Data	-5.745
Mean	0.00311	Mean of log Data	-5.773
Median	0.0031	SD of log Data	0.01
SD	3.162E-05		
Std. Error of Mean	0.00001		
Coefficient of Variation	0.0102		
Skewness	3.162		

Warning: There are only 2 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.366	Shapiro Wilk Test Statistic	0.366
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.00313	95% H-UCL	N/A
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00315
95% Adjusted-CLT UCL (Chen-1995)	0.00314	97.5% Chebyshev (MVUE) UCL	0.00317
95% Modified-t UCL (Johnson-1978)	0.00313	99% Chebyshev (MVUE) UCL	0.00321

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	7651	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	4.065E-07		
MLE of Mean	0.00311		
MLE of Standard Deviation	3.555E-05		
nu star	153026		
Approximate Chi Square Value (.05)	152117	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.00313
Adjusted Chi Square Value	151959	95% Jackknife UCL	N/A
		95% Standard Bootstrap UCL	N/A
Anderson-Darling Test Statistic	4.346	95% Bootstrap-t UCL	N/A
Anderson-Darling 5% Critical Value	0.724	95% Hall's Bootstrap UCL	N/A
Kolmogorov-Smirnov Test Statistic	0.628	95% Percentile Bootstrap UCL	N/A
Kolmogorov-Smirnov 5% Critical Value	0.266	95% BCA Bootstrap UCL	N/A
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.00315
		97.5% Chebyshev(Mean, Sd) UCL	0.00317
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.00321
95% Approximate Gamma UCL	0.00313		
95% Adjusted Gamma UCL	0.00313		

Potential UCL to Use	
Use 95% Student's-t UCL	0.00313
or 95% Modified-t UCL	0.00313

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (dro)

General Statistics

Number of Valid Observations	12	Number of Distinct Observations	9

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.18	Minimum of Log Data	-1.715
Maximum	1.92	Maximum of Log Data	0.652
Mean	0.718	Mean of log Data	-0.729
Median	0.385	SD of log Data	0.932
SD	0.66		
Std. Error of Mean	0.191		
Coefficient of Variation	0.919		
Skewness	1.01		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.787	Shapiro Wilk Test Statistic	0.851
Shapiro Wilk Critical Value	0.859	Shapiro Wilk Critical Value	0.859
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	1.061	95% H-UCL	1.634
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.597
95% Adjusted-CLT UCL (Chen-1995)	1.091	97.5% Chebyshev (MVUE) UCL	1.98
95% Modified-t UCL (Johnson-1978)	1.07	99% Chebyshev (MVUE) UCL	2.734

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	1.104	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.651		
MLE of Mean	0.718		
MLE of Standard Deviation	0.684		
nu star	26.5		
Approximate Chi Square Value (.05)	15.77	**Nonparametric Statistics**	
Adjusted Level of Significance	0.029	95% CLT UCL	1.032
Adjusted Chi Square Value	14.52	95% Jackknife UCL	1.061
		95% Standard Bootstrap UCL	1.004
Anderson-Darling Test Statistic	0.848	95% Bootstrap-t UCL	1.182
Anderson-Darling 5% Critical Value	0.748	95% Hall's Bootstrap UCL	1.019
Kolmogorov-Smirnov Test Statistic	0.27	95% Percentile Bootstrap UCL	1.05
Kolmogorov-Smirnov 5% Critical Value	0.25	95% BCA Bootstrap UCL	1.061
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1.549
		97.5% Chebyshev(Mean, Sd) UCL	1.909
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	2.615
95% Approximate Gamma UCL	1.208		
95% Adjusted Gamma UCL	1.312		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	1.549

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (fluoranthene)

General Statistics

Number of Valid Observations	2	Number of Distinct Observations	1

Warning: This data set only has 2 observations!
Data set is too small to compute reliable and meaningful statistics and estimates!
The data set for variable Result (1/2 DL for NDs) (fluoranthene) was not processed!

It is suggested to collect at least 8 to 10 observations before using these statistical methods!
If possible, compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Result (1/2 DL for NDs) (fluorene)

General Statistics

Number of Valid Observations	2	Number of Distinct Observations	1

Warning: This data set only has 2 observations!
Data set is too small to compute reliable and meaningful statistics and estimates!
The data set for variable Result (1/2 DL for NDs) (fluorene) was not processed!

It is suggested to collect at least 8 to 10 observations before using these statistical methods!
If possible, compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Result (1/2 DL for NDs) (gro)

General Statistics

Number of Valid Observations	12	Number of Distinct Observations	6

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.031	Minimum of Log Data	-3.474
Maximum	20.8	Maximum of Log Data	3.035
Mean	2.311	Mean of log Data	-1.847
Median	0.0405	SD of log Data	2.36
SD	5.946		
Std. Error of Mean	1.717		
Coefficient of Variation	2.573		
Skewness	3.23		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.452	Shapiro Wilk Test Statistic	0.732
Shapiro Wilk Critical Value	0.859	Shapiro Wilk Critical Value	0.859
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	5.394	95% H-UCL	153
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	5.856
95% Adjusted-CLT UCL (Chen-1995)	6.845	97.5% Chebyshev (MVUE) UCL	7.775
95% Modified-t UCL (Johnson-1978)	5.661	99% Chebyshev (MVUE) UCL	11.55

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.252	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	9.156		
MLE of Mean	2.311		
MLE of Standard Deviation	4.6		
nu star	6.058		
Approximate Chi Square Value (.05)	1.67	**Nonparametric Statistics**	
Adjusted Level of Significance	0.029	95% CLT UCL	5.135
Adjusted Chi Square Value	1.344	95% Jackknife UCL	5.394
		95% Standard Bootstrap UCL	5.035
Anderson-Darling Test Statistic	1.775	95% Bootstrap-t UCL	23.31
Anderson-Darling 5% Critical Value	0.839	95% Hall's Bootstrap UCL	22.28
Kolmogorov-Smirnov Test Statistic	0.382	95% Percentile Bootstrap UCL	5.556
Kolmogorov-Smirnov 5% Critical Value	0.267	95% BCA Bootstrap UCL	7.387
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	9.794
		97.5% Chebyshev(Mean, Sd) UCL	13.03
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	19.39
95% Approximate Gamma UCL	8.385		
95% Adjusted Gamma UCL	10.42		

Potential UCL to Use	
Use 99% Chebyshev (Mean, Sd) UCL	19.39

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (hardness as caco3)

General Statistics

Number of Valid Observations	6	Number of Distinct Observations	6

Raw Statistics		Log-transformed Statistics	
Minimum	166	Minimum of Log Data	5.112
Maximum	191	Maximum of Log Data	5.252
Mean	181.3	Mean of log Data	5.199
Median	186.5	SD of log Data	0.0636
SD	11.31		
Std. Error of Mean	4.616		
Coefficient of Variation	0.0624		
Skewness	-0.846		

Warning: A sample size of 'n' = 6 may not adequate enough to compute meaningful and reliable test statistics and estimates!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Warning: There are only 6 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set,
the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.793	Shapiro Wilk Test Statistic	0.788
Shapiro Wilk Critical Value	0.788	Shapiro Wilk Critical Value	0.788
Data appear Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	190.6	95% H-UCL	N/A
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	201.8
95% Adjusted-CLT UCL (Chen-1995)	187.2	97.5% Chebyshev (MVUE) UCL	210.7
95% Modified-t UCL (Johnson-1978)	190.4	99% Chebyshev (MVUE) UCL	228.2

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	150.6	**Data appear Normal at 5% Significance Level**	
Theta Star	1.204		
MLE of Mean	181.3		
MLE of Standard Deviation	14.78		
nu star	1807		
Approximate Chi Square Value (.05)	1709	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0122	95% CLT UCL	188.9
Adjusted Chi Square Value	1674	95% Jackknife UCL	190.6
		95% Standard Bootstrap UCL	188.4
Anderson-Darling Test Statistic	0.722	95% Bootstrap-t UCL	188.7
Anderson-Darling 5% Critical Value	0.696	95% Hall's Bootstrap UCL	185.9
Kolmogorov-Smirnov Test Statistic	0.31	95% Percentile Bootstrap UCL	188
Kolmogorov-Smirnov 5% Critical Value	0.332	95% BCA Bootstrap UCL	187.5
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	201.5
		97.5% Chebyshev(Mean, Sd) UCL	210.2
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	227.3
95% Approximate Gamma UCL	191.7		
95% Adjusted Gamma UCL	195.7		

Potential UCL to Use	
Use 95% Student's-t UCL	190.6

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Note: For highly negative-skewed data, confidence limits
(e.g., Chen, Johnson, Lognormal, and Gamma) may not be
reliable. Chen's and Johnson's methods provide
adjustments for positvely skewed data sets.

Result (1/2 DL for NDs) (hco3 alkalinity)

General Statistics

Number of Valid Observations	6	Number of Distinct Observations	5

Raw Statistics		**Log-transformed Statistics**	
Minimum	147	Minimum of Log Data	4.99
Maximum	185	Maximum of Log Data	5.22
Mean	162.3	Mean of log Data	5.087
Median	164.5	SD of log Data	0.0867
SD	14.19		
Std. Error of Mean	5.795		
Coefficient of Variation	0.0874		
Skewness	0.473		

Warning: A sample size of 'n' = 6 may not adequate enough to compute meaningful and reliable test statistics and estimates!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Warning: There are only 6 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set,
the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.885	Shapiro Wilk Test Statistic	0.886
Shapiro Wilk Critical Value	0.788	Shapiro Wilk Critical Value	0.788
Data appear Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	174	95% H-UCL	N/A
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	187.4
95% Adjusted-CLT UCL (Chen-1995)	173.1	97.5% Chebyshev (MVUE) UCL	198.2
95% Modified-t UCL (Johnson-1978)	174.2	99% Chebyshev (MVUE) UCL	219.5

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	79.6	**Data appear Normal at 5% Significance Level**	
Theta Star	2.039		
MLE of Mean	162.3		
MLE of Standard Deviation	18.19		
nu star	955.2		
Approximate Chi Square Value (.05)	884.5	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0122	95% CLT UCL	171.9
Adjusted Chi Square Value	859.6	95% Jackknife UCL	174
		95% Standard Bootstrap UCL	170.8
Anderson-Darling Test Statistic	0.456	95% Bootstrap-t UCL	175.9
Anderson-Darling 5% Critical Value	0.696	95% Hall's Bootstrap UCL	173.2
Kolmogorov-Smirnov Test Statistic	0.228	95% Percentile Bootstrap UCL	171.8
Kolmogorov-Smirnov 5% Critical Value	0.332	95% BCA Bootstrap UCL	171.8
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	187.6
		97.5% Chebyshev(Mean, Sd) UCL	198.5
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	220
95% Approximate Gamma UCL	175.3		
95% Adjusted Gamma UCL	180.4		

Potential UCL to Use	
Use 95% Student's-t UCL	174

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (indeno(1,2,3-cd)pyrene)

General Statistics

Number of Valid Observations	11	Number of Distinct Observations	4

Raw Statistics		Log-transformed Statistics	
Minimum	0.000015	Minimum of Log Data	-11.11
Maximum	0.000025	Maximum of Log Data	-10.6
Mean	1.604E-05	Mean of log Data	-11.05
Median	0.000015	SD of log Data	0.152
SD	2.986E-06		
Std. Error of Mean	9.004E-07		
Coefficient of Variation	N/A		
Skewness	3.264		

Warning: There are only 4 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.404	Shapiro Wilk Test Statistic	0.42
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	1.767E-05	95% H-UCL	1.75E-05
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.923E-05
95% Adjusted-CLT UCL (Chen-1995)	1.846E-05	97.5% Chebyshev (MVUE) UCL	2.062E-05
95% Modified-t UCL (Johnson-1978)	1.782E-05	99% Chebyshev (MVUE) UCL	2.335E-05

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	30.28	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	5.296E-07		
MLE of Mean	1.604E-05		
MLE of Standard Deviation	2.914E-06		
nu star	666.2		
Approximate Chi Square Value (.05)	607.3	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0278	95% CLT UCL	1.752E-05
Adjusted Chi Square Value	598.1	95% Jackknife UCL	1.767E-05
		95% Standard Bootstrap UCL	1.746E-05
Anderson-Darling Test Statistic	3.079	95% Bootstrap-t UCL	2.797E-05
Anderson-Darling 5% Critical Value	0.728	95% Hall's Bootstrap UCL	2.811E-05
Kolmogorov-Smirnov Test Statistic	0.427	95% Percentile Bootstrap UCL	1.778E-05
Kolmogorov-Smirnov 5% Critical Value	0.255	95% BCA Bootstrap UCL	1.871E-05
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1.996E-05
		97.5% Chebyshev(Mean, Sd) UCL	2.166E-05
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	2.5E-05
95% Approximate Gamma UCL	1.759E-05		
95% Adjusted Gamma UCL	1.786E-05		

Potential UCL to Use	
Use 95% Student's-t UCL	1.767E-05
or 95% Modified-t UCL	1.782E-05

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (iron)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	9

Raw Statistics		Log-transformed Statistics	
Minimum	0.31	Minimum of Log Data	-1.171
Maximum	50.1	Maximum of Log Data	3.914
Mean	11.38	Mean of log Data	1.501
Median	4.715	SD of log Data	1.685
SD	15.11		
Std. Error of Mean	4.778		
Coefficient of Variation	1.327		
Skewness	2.174		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.728	Shapiro Wilk Test Statistic	0.922
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	20.14	95% H-UCL	251
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	49.12
95% Adjusted-CLT UCL (Chen-1995)	22.75	97.5% Chebyshev (MVUE) UCL	64.19
95% Modified-t UCL (Johnson-1978)	20.69	99% Chebyshev (MVUE) UCL	93.79

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.525	**Data appear Gamma Distributed at 5% Significance Level**	
Theta Star	21.66		
MLE of Mean	11.38		
MLE of Standard Deviation	15.7		
nu star	10.51		
Approximate Chi Square Value (.05)	4.263	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	19.24
Adjusted Chi Square Value	3.598	95% Jackknife UCL	20.14
		95% Standard Bootstrap UCL	18.88
Anderson-Darling Test Statistic	0.272	95% Bootstrap-t UCL	31.86
Anderson-Darling 5% Critical Value	0.765	95% Hall's Bootstrap UCL	47.15
Kolmogorov-Smirnov Test Statistic	0.171	95% Percentile Bootstrap UCL	19.61
Kolmogorov-Smirnov 5% Critical Value	0.278	95% BCA Bootstrap UCL	23.4
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	32.21
		97.5% Chebyshev(Mean, Sd) UCL	41.22
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	58.92
95% Approximate Gamma UCL	28.06		
95% Adjusted Gamma UCL	33.25		

Potential UCL to Use	Use 95% Approximate Gamma UCL	28.06

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (isopropanol (propanol))

General Statistics

Number of Valid Observations	8	Number of Distinct Observations	1

Warning: There is only one distinct observation value in this data set - resulting in '0' variance!
ProUCL (or any other software) should not be used on such a data set!
The data set for variable Result (1/2 DL for NDs) (isopropanol (propanol)) was not processed!

If possible, compute and collect Data Quality Objectives (DQOs) based sample size and analytical results.
The Project Team may decide to use alternative site specific values to estimate environmental parameters (e.g., EPC, BTV).

Result (1/2 DL for NDs) (lead)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	3

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.00031	Minimum of Log Data	-8.079
Maximum	0.00118	Maximum of Log Data	-6.742
Mean	0.0004205	Mean of log Data	-7.889
Median	0.00031	SD of log Data	0.44
SD	0.0002769		
Std. Error of Mean	8.756E-05		
Coefficient of Variation	0.658		
Skewness	2.808		

Warning: There are only 3 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.482	Shapiro Wilk Test Statistic	0.521
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.000581	95% H-UCL	0.0005653
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0006603
95% Adjusted-CLT UCL (Chen-1995)	0.0006476	97.5% Chebyshev (MVUE) UCL	0.0007692
95% Modified-t UCL (Johnson-1978)	0.000594	99% Chebyshev (MVUE) UCL	0.000983
Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	3.228	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0001303		
MLE of Mean	0.0004205		
MLE of Standard Deviation	0.0002341		
nu star	64.56		
Approximate Chi Square Value (.05)	47.07	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.0005645
Adjusted Chi Square Value	44.49	95% Jackknife UCL	0.000581
		95% Standard Bootstrap UCL	N/A
Anderson-Darling Test Statistic	2.455	95% Bootstrap-t UCL	N/A
Anderson-Darling 5% Critical Value	0.729	95% Hall's Bootstrap UCL	N/A
Kolmogorov-Smirnov Test Statistic	0.476	95% Percentile Bootstrap UCL	N/A
Kolmogorov-Smirnov 5% Critical Value	0.268	95% BCA Bootstrap UCL	N/A
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0008022
		97.5% Chebyshev(Mean, Sd) UCL	0.0009673
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.00129
95% Approximate Gamma UCL	0.0005767		
95% Adjusted Gamma UCL	0.0006102		
Potential UCL to Use		Use 95% Student's-t UCL	0.000581
		or 95% Modified-t UCL	0.000594

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (methyl tert-butyl ether (mtbe))

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	5

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.000144	Minimum of Log Data	-8.846
Maximum	0.00387	Maximum of Log Data	-5.555
Mean	0.0012	Mean of log Data	-7.375
Median	0.00111	SD of log Data	1.332
SD	0.00122		
Std. Error of Mean	0.0003847		
Coefficient of Variation	1.016		
Skewness	1.215		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.837	Shapiro Wilk Test Statistic	0.82
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0019	95% H-UCL	0.00831
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0039
95% Adjusted-CLT UCL (Chen-1995)	0.00199	97.5% Chebyshev (MVUE) UCL	0.00501
95% Modified-t UCL (Johnson-1978)	0.00193	99% Chebyshev (MVUE) UCL	0.0072

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.698	**Data appear Gamma Distributed at 5% Significance Level**	
Theta Star	0.00171		
MLE of Mean	0.0012		
MLE of Standard Deviation	0.00143		
nu star	13.97		
Approximate Chi Square Value (.05)	6.548	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.00183
Adjusted Chi Square Value	5.689	95% Jackknife UCL	0.0019
		95% Standard Bootstrap UCL	0.00179
Anderson-Darling Test Statistic	0.708	95% Bootstrap-t UCL	0.00217
Anderson-Darling 5% Critical Value	0.752	95% Hall's Bootstrap UCL	0.0024
Kolmogorov-Smirnov Test Statistic	0.267	95% Percentile Bootstrap UCL	0.00179
Kolmogorov-Smirnov 5% Critical Value	0.275	95% BCA Bootstrap UCL	0.002
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.00287
		97.5% Chebyshev(Mean, Sd) UCL	0.0036
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.00503
95% Approximate Gamma UCL	0.00255		
95% Adjusted Gamma UCL	0.00294		

Potential UCL to Use			
		Use 95% Approximate Gamma UCL	0.00255

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (methylene chloride)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	3

Raw Statistics		Log-transformed Statistics	
Minimum	0.000152	Minimum of Log Data	-8.792
Maximum	0.001	Maximum of Log Data	-6.908
Mean	0.0004672	Mean of log Data	-8.066
Median	0.000152	SD of log Data	0.941
SD	0.0004128		
Std. Error of Mean	0.0001305		
Coefficient of Variation	0.884		
Skewness	0.575		

Warning: There are only 3 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.681	Shapiro Wilk Test Statistic	0.665
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0007065	95% H-UCL	0.00125
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00109
95% Adjusted-CLT UCL (Chen-1995)	0.0007073	97.5% Chebyshev (MVUE) UCL	0.00136
95% Modified-t UCL (Johnson-1978)	0.0007104	99% Chebyshev (MVUE) UCL	0.00189

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	1.049	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0004453		
MLE of Mean	0.0004672		
MLE of Standard Deviation	0.0004561		
nu star	20.98		
Approximate Chi Square Value (.05)	11.58	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.0006819
Adjusted Chi Square Value	10.38	95% Jackknife UCL	0.0007065
		95% Standard Bootstrap UCL	N/A
Anderson-Darling Test Statistic	1.692	95% Bootstrap-t UCL	N/A
Anderson-Darling 5% Critical Value	0.741	95% Hall's Bootstrap UCL	N/A
Kolmogorov-Smirnov Test Statistic	0.394	95% Percentile Bootstrap UCL	N/A
Kolmogorov-Smirnov 5% Critical Value	0.272	95% BCA Bootstrap UCL	N/A
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.00104
		97.5% Chebyshev(Mean, Sd) UCL	0.00128
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.00177
95% Approximate Gamma UCL	0.0008467		
95% Adjusted Gamma UCL	0.000944		

Potential UCL to Use		
	Use 95% Chebyshev (Mean, Sd) UCL	0.00104

Recommended UCL exceeds the maximum observation

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (naphthalene)

General Statistics

Number of Valid Observations	11	Number of Distinct Observations	10

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.000031	Minimum of Log Data	-10.38
Maximum	0.178	Maximum of Log Data	-1.726
Mean	0.0217	Mean of log Data	-7.652
Median	0.0000842	SD of log Data	3.332
SD	0.0531		
Std. Error of Mean	0.016		
Coefficient of Variation	2.445		
Skewness	3.063		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.479	Shapiro Wilk Test Statistic	0.791
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0507	95% H-UCL	746.1
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.112
95% Adjusted-CLT UCL (Chen-1995)	0.0638	97.5% Chebyshev (MVUE) UCL	0.151
95% Modified-t UCL (Johnson-1978)	0.0532	99% Chebyshev (MVUE) UCL	0.227

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.201	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.108		
MLE of Mean	0.0217		
MLE of Standard Deviation	0.0483		
nu star	4.431		
Approximate Chi Square Value (.05)	0.899	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0278	95% CLT UCL	0.048
Adjusted Chi Square Value	0.673	95% Jackknife UCL	0.0507
		95% Standard Bootstrap UCL	0.0461
Anderson-Darling Test Statistic	1.274	95% Bootstrap-t UCL	0.142
Anderson-Darling 5% Critical Value	0.862	95% Hall's Bootstrap UCL	0.145
Kolmogorov-Smirnov Test Statistic	0.337	95% Percentile Bootstrap UCL	0.0514
Kolmogorov-Smirnov 5% Critical Value	0.282	95% BCA Bootstrap UCL	0.0673
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0914
		97.5% Chebyshev(Mean, Sd) UCL	0.122
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.181
95% Approximate Gamma UCL	0.107		
95% Adjusted Gamma UCL	0.143		

Potential UCL to Use		
		Use 95% Hall's Bootstrap UCL 0.145

In Case Bootstrap t and/or Hall's Bootstrap yields an unreasonably large UCL value, use 97.5% or 99% Chebyshev (Mean, Sd) UCL

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (n-hexane)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	5

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0000723	Minimum of Log Data	-9.535
Maximum	0.0648	Maximum of Log Data	-2.736
Mean	0.0102	Mean of log Data	-7.67
Median	0.0000723	SD of log Data	2.77
SD	0.0215		
Std. Error of Mean	0.00679		
Coefficient of Variation	2.104		
Skewness	2.307		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.567	Shapiro Wilk Test Statistic	0.71
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0226	95% H-UCL	18.12
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0345
95% Adjusted-CLT UCL (Chen-1995)	0.0267	97.5% Chebyshev (MVUE) UCL	0.0462
95% Modified-t UCL (Johnson-1978)	0.0235	99% Chebyshev (MVUE) UCL	0.0691

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.23	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0444		
MLE of Mean	0.0102		
MLE of Standard Deviation	0.0213		
nu star	4.593		
Approximate Chi Square Value (.05)	0.969	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.0214
Adjusted Chi Square Value	0.717	95% Jackknife UCL	0.0226
		95% Standard Bootstrap UCL	0.0207
Anderson-Darling Test Statistic	1.531	95% Bootstrap-t UCL	0.13
Anderson-Darling 5% Critical Value	0.841	95% Hall's Bootstrap UCL	0.161
Kolmogorov-Smirnov Test Statistic	0.354	95% Percentile Bootstrap UCL	0.0226
Kolmogorov-Smirnov 5% Critical Value	0.292	95% BCA Bootstrap UCL	0.0263
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0398
		97.5% Chebyshev(Mean, Sd) UCL	0.0526
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0778
95% Approximate Gamma UCL	0.0484		
95% Adjusted Gamma UCL	0.0654		

Potential UCL to Use		
	Use 99% Chebyshev (Mean, Sd) UCL	0.0778

Recommended UCL exceeds the maximum observation

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (nitrate)

General Statistics

Number of Valid Observations	6	Number of Distinct Observations	3

Raw Statistics		Log-transformed Statistics	
Minimum	0.031	Minimum of Log Data	-3.474
Maximum	0.0577	Maximum of Log Data	-2.852
Mean	0.0387	Mean of log Data	-3.29
Median	0.031	SD of log Data	0.288
SD	0.0121		
Std. Error of Mean	0.00493		
Coefficient of Variation	0.313		
Skewness	1.132		

Warning: There are only 3 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Warning: A sample size of 'n' = 6 may not adequate enough to compute meaningful and reliable test statistics and estimates!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.697	Shapiro Wilk Test Statistic	0.688
Shapiro Wilk Critical Value	0.788	Shapiro Wilk Critical Value	0.788
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0486	95% H-UCL	0.0516
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0583
95% Adjusted-CLT UCL (Chen-1995)	0.0492	97.5% Chebyshev (MVUE) UCL	0.0669
95% Modified-t UCL (Johnson-1978)	0.049	99% Chebyshev (MVUE) UCL	0.0837

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	7.01	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.00551		
MLE of Mean	0.0387		
MLE of Standard Deviation	0.0146		
nu star	84.12		
Approximate Chi Square Value (.05)	63.98	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0122	95% CLT UCL	0.0468
Adjusted Chi Square Value	57.67	95% Jackknife UCL	0.0486
		95% Standard Bootstrap UCL	N/A
Anderson-Darling Test Statistic	1.078	95% Bootstrap-t UCL	N/A
Anderson-Darling 5% Critical Value	0.698	95% Hall's Bootstrap UCL	N/A
Kolmogorov-Smirnov Test Statistic	0.424	95% Percentile Bootstrap UCL	N/A
Kolmogorov-Smirnov 5% Critical Value	0.332	95% BCA Bootstrap UCL	N/A
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0602
		97.5% Chebyshev(Mean, Sd) UCL	0.0695
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0877
95% Approximate Gamma UCL	0.0508		
95% Adjusted Gamma UCL	0.0564		

Potential UCL to Use	
Use 95% Student's-t UCL	0.0486
or 95% Modified-t UCL	0.049

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (nitrite)

General Statistics

Number of Valid Observations	6	Number of Distinct Observations	1

Warning: There is only one distinct observation value in this data set - resulting in '0' variance!
ProUCL (or any other software) should not be used on such a data set!
The data set for variable Result (1/2 DL for NDs) (nitrite) was not processed!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible, compute and collect Data Quality Objectives (DQOs) based sample size and analytical results.
The Project Team may decide to use alternative site specific values to estimate environmental parameters (e.g., EPC, BTV).

Result (1/2 DL for NDs) (n-propylbenzene)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	5

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.000113	Minimum of Log Data	-9.088
Maximum	0.0803	Maximum of Log Data	-2.522
Mean	0.0166	Mean of log Data	-7.026
Median	0.000113	SD of log Data	2.863
SD	0.0301		
Std. Error of Mean	0.00953		
Coefficient of Variation	1.82		
Skewness	1.705		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.622	Shapiro Wilk Test Statistic	0.716
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.034	95% H-UCL	70.24
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0782
95% Adjusted-CLT UCL (Chen-1995)	0.0377	97.5% Chebyshev (MVUE) UCL	0.105
95% Modified-t UCL (Johnson-1978)	0.0349	99% Chebyshev (MVUE) UCL	0.157
Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.237	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0698		
MLE of Mean	0.0166		
MLE of Standard Deviation	0.034		
nu star	4.747		
Approximate Chi Square Value (.05)	1.037	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.0322
Adjusted Chi Square Value	0.772	95% Jackknife UCL	0.034
		95% Standard Bootstrap UCL	0.0314
Anderson-Darling Test Statistic	1.405	95% Bootstrap-t UCL	0.089
Anderson-Darling 5% Critical Value	0.836	95% Hall's Bootstrap UCL	0.128
Kolmogorov-Smirnov Test Statistic	0.369	95% Percentile Bootstrap UCL	0.031
Kolmogorov-Smirnov 5% Critical Value	0.291	95% BCA Bootstrap UCL	0.0374
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0581
		97.5% Chebyshev(Mean, Sd) UCL	0.0761
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.111
95% Approximate Gamma UCL	0.0758		
95% Adjusted Gamma UCL	0.102		

Potential UCL to Use		
	Use 99% Chebyshev (Mean, Sd) UCL	0.111

Recommended UCL exceeds the maximum observation

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (oh alkalinity)

General Statistics

Number of Valid Observations 6 Number of Distinct Observations 1

Warning: There is only one distinct observation value in this data set - resulting in '0' variance!
ProUCL (or any other software) should not be used on such a data set!
The data set for variable Result (1/2 DL for NDs) (oh alkalinity) was not processed!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible, compute and collect Data Quality Objectives (DQOs) based sample size and analytical results.
The Project Team may decide to use alternative site specific values to estimate environmental parameters (e.g., EPC, BTV).

Result (1/2 DL for NDs) (phenanthrene)

General Statistics

Number of Valid Observations 2 Number of Distinct Observations 1

Warning: This data set only has 2 observations!
Data set is too small to compute reliable and meaningful statistics and estimates!
The data set for variable Result (1/2 DL for NDs) (phenanthrene) was not processed!

It is suggested to collect at least 8 to 10 observations before using these statistical methods!
If possible, compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Result (1/2 DL for NDs) (propylene glycol (1,2,-propanediol))

General Statistics

Number of Valid Observations 9 Number of Distinct Observations 1

Warning: There is only one distinct observation value in this data set - resulting in '0' variance!
ProUCL (or any other software) should not be used on such a data set!
The data set for variable Result (1/2 DL for NDs) (propylene glycol (1,2,-propanediol)) was not processed!

If possible, compute and collect Data Quality Objectives (DQOs) based sample size and analytical results.
The Project Team may decide to use alternative site specific values to estimate environmental parameters (e.g., EPC, BTV).

Result (1/2 DL for NDs) (pyrene)

General Statistics

Number of Valid Observations 2 Number of Distinct Observations 1

Warning: This data set only has 2 observations!
Data set is too small to compute reliable and meaningful statistics and estimates!
The data set for variable Result (1/2 DL for NDs) (pyrene) was not processed!

It is suggested to collect at least 8 to 10 observations before using these statistical methods!
If possible, compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Result (1/2 DL for NDs) (rro)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	4

Raw Statistics		Log-transformed Statistics	
Minimum	0.15	Minimum of Log Data	-1.897
Maximum	0.278	Maximum of Log Data	-1.28
Mean	0.168	Mean of log Data	-1.801
Median	0.15	SD of log Data	0.197
SD	0.0403		
Std. Error of Mean	0.0127		
Coefficient of Variation	0.239		
Skewness	2.715		

Warning: There are only 4 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.543	Shapiro Wilk Test Statistic	0.58
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.192	95% H-UCL	0.19
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.214
95% Adjusted-CLT UCL (Chen-1995)	0.201	97.5% Chebyshev (MVUE) UCL	0.233
95% Modified-t UCL (Johnson-1978)	0.194	99% Chebyshev (MVUE) UCL	0.272

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	17.85	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.00943		
MLE of Mean	0.168		
MLE of Standard Deviation	0.0399		
nu star	357.1		
Approximate Chi Square Value (.05)	314.3	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.189
Adjusted Chi Square Value	307.3	95% Jackknife UCL	0.192
		95% Standard Bootstrap UCL	0.188
Anderson-Darling Test Statistic	1.97	95% Bootstrap-t UCL	0.231
Anderson-Darling 5% Critical Value	0.725	95% Hall's Bootstrap UCL	0.255
Kolmogorov-Smirnov Test Statistic	0.393	95% Percentile Bootstrap UCL	0.192
Kolmogorov-Smirnov 5% Critical Value	0.266	95% BCA Bootstrap UCL	0.2
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.224
		97.5% Chebyshev(Mean, Sd) UCL	0.248
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.295
95% Approximate Gamma UCL	0.191		
95% Adjusted Gamma UCL	0.196		

Potential UCL to Use	
Use 95% Student's-t UCL	0.192
or 95% Modified-t UCL	0.194

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (selenium)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	6

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0015	Minimum of Log Data	-6.502
Maximum	0.00218	Maximum of Log Data	-6.128
Mean	0.00174	Mean of log Data	-6.362
Median	0.00178	SD of log Data	0.134
SD	0.0002365		
Std. Error of Mean	7.479E-05		
Coefficient of Variation	0.136		
Skewness	0.449		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.872	Shapiro Wilk Test Statistic	0.867
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data appear Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.00188	95% H-UCL	0.00189
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00206
95% Adjusted-CLT UCL (Chen-1995)	0.00187	97.5% Chebyshev (MVUE) UCL	0.0022
95% Modified-t UCL (Johnson-1978)	0.00188	99% Chebyshev (MVUE) UCL	0.00248

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	43	**Data appear Normal at 5% Significance Level**	
Theta Star	4.046E-05		
MLE of Mean	0.00174		
MLE of Standard Deviation	0.0002653		
nu star	860		
Approximate Chi Square Value (.05)	793	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	0.00186
Adjusted Chi Square Value	781.7	95% Jackknife UCL	0.00188
		95% Standard Bootstrap UCL	0.00186
Anderson-Darling Test Statistic	0.636	95% Bootstrap-t UCL	0.00189
Anderson-Darling 5% Critical Value	0.724	95% Hall's Bootstrap UCL	0.00187
Kolmogorov-Smirnov Test Statistic	0.262	95% Percentile Bootstrap UCL	0.00187
Kolmogorov-Smirnov 5% Critical Value	0.266	95% BCA Bootstrap UCL	0.00187
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.00207
		97.5% Chebyshev(Mean, Sd) UCL	0.00221
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.00248
95% Approximate Gamma UCL	0.00189		
95% Adjusted Gamma UCL	0.00191		

Potential UCL to Use	
Use 95% Student's-t UCL	0.00188

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (sulfate)

General Statistics

Number of Valid Observations	6	Number of Distinct Observations	6

Raw Statistics		Log-transformed Statistics	
Minimum	18.8	Minimum of Log Data	2.934
Maximum	37.2	Maximum of Log Data	3.616
Mean	28.97	Mean of log Data	3.331
Median	30.6	SD of log Data	0.296
SD	7.934		
Std. Error of Mean	3.239		
Coefficient of Variation	0.274		
Skewness	-0.444		

Warning: A sample size of 'n' = 6 may not adequate enough to compute meaningful and reliable test statistics and estimates!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Warning: There are only 6 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set,
the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.88	Shapiro Wilk Test Statistic	0.858
Shapiro Wilk Critical Value	0.788	Shapiro Wilk Critical Value	0.788
Data appear Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	35.49	95% H-UCL	39.21
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	44.29
95% Adjusted-CLT UCL (Chen-1995)	33.67	97.5% Chebyshev (MVUE) UCL	50.91
95% Modified-t UCL (Johnson-1978)	35.4	99% Chebyshev (MVUE) UCL	63.89

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	7.398	**Data appear Normal at 5% Significance Level**	
Theta Star	3.916		
MLE of Mean	28.97		
MLE of Standard Deviation	10.65		
nu star	88.77		
Approximate Chi Square Value (.05)	68.05	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0122	95% CLT UCL	34.29
Adjusted Chi Square Value	61.53	95% Jackknife UCL	35.49
		95% Standard Bootstrap UCL	33.76
Anderson-Darling Test Statistic	0.469	95% Bootstrap-t UCL	34.5
Anderson-Darling 5% Critical Value	0.698	95% Hall's Bootstrap UCL	32.6
Kolmogorov-Smirnov Test Statistic	0.224	95% Percentile Bootstrap UCL	33.78
Kolmogorov-Smirnov 5% Critical Value	0.332	95% BCA Bootstrap UCL	33.58
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	43.09
		97.5% Chebyshev(Mean, Sd) UCL	49.19
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	61.19
95% Approximate Gamma UCL	37.79		
95% Adjusted Gamma UCL	41.79		

Potential UCL to Use		
	Use 95% Student's-t UCL	35.49

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Note: For highly negative-skewed data, confidence limits
(e.g., Chen, Johnson, Lognormal, and Gamma) may not be
reliable. Chen's and Johnson's methods provide
adjustments for positvely skewed data sets.

Result (1/2 DL for NDs) (total kjeldahl nitrogen)

General Statistics

Number of Valid Observations	6	Number of Distinct Observations	3

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.31	Minimum of Log Data	-1.171
Maximum	0.631	Maximum of Log Data	-0.46
Mean	0.395	Mean of log Data	-0.974
Median	0.31	SD of log Data	0.314
SD	0.138		
Std. Error of Mean	0.0562		
Coefficient of Variation	0.349		
Skewness	1.363		

Warning: There are only 3 Distinct Values in this data
There are insufficient Distinct Values to perform some GOF tests and bootstrap methods.
Those methods will return a 'N/A' value on your output display!

It is necessary to have 4 or more Distinct Values to compute bootstrap methods.
However, results obtained using 4 to 9 distinct values may not be reliable.
It is recommended to have 10-15 or more observations for accurate and meaningful bootstrap results.

Warning: A sample size of 'n' = 6 may not adequate enough to compute meaningful and reliable test statistics and estimates!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.706	Shapiro Wilk Test Statistic	0.703
Shapiro Wilk Critical Value	0.788	Shapiro Wilk Critical Value	0.788
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.508	95% H-UCL	0.544
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.613
95% Adjusted-CLT UCL (Chen-1995)	0.52	97.5% Chebyshev (MVUE) UCL	0.708
95% Modified-t UCL (Johnson-1978)	0.513	99% Chebyshev (MVUE) UCL	0.895

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	5.842	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0675		
MLE of Mean	0.395		
MLE of Standard Deviation	0.163		
nu star	70.1		
Approximate Chi Square Value (.05)	51.83	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0122	95% CLT UCL	0.487
Adjusted Chi Square Value	46.2	95% Jackknife UCL	0.508
		95% Standard Bootstrap UCL	N/A
Anderson-Darling Test Statistic	1.02	95% Bootstrap-t UCL	N/A
Anderson-Darling 5% Critical Value	0.698	95% Hall's Bootstrap UCL	N/A
Kolmogorov-Smirnov Test Statistic	0.42	95% Percentile Bootstrap UCL	N/A
Kolmogorov-Smirnov 5% Critical Value	0.332	95% BCA Bootstrap UCL	N/A
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.64
		97.5% Chebyshev(Mean, Sd) UCL	0.746
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.954
95% Approximate Gamma UCL	0.534		
95% Adjusted Gamma UCL	0.599		

Potential UCL to Use	
Use 95% Student's-t UCL	0.508
or 95% Modified-t UCL	0.513

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (total organic carbon)

General Statistics

Number of Valid Observations	6	Number of Distinct Observations	6

Raw Statistics		Log-transformed Statistics	
Minimum	2.17	Minimum of Log Data	0.775
Maximum	10.3	Maximum of Log Data	2.332
Mean	4.322	Mean of log Data	1.317
Median	3.34	SD of log Data	0.549
SD	3.013		
Std. Error of Mean	1.23		
Coefficient of Variation	0.697		
Skewness	2.153		

Warning: A sample size of 'n' = 6 may not adequate enough to compute meaningful and reliable test statistics and estimates!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Warning: There are only 6 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set,
the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.718	Shapiro Wilk Test Statistic	0.874
Shapiro Wilk Critical Value	0.788	Shapiro Wilk Critical Value	0.788
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	6.8	95% H-UCL	8.529
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	8.331
95% Adjusted-CLT UCL (Chen-1995)	7.501	97.5% Chebyshev (MVUE) UCL	10.11
95% Modified-t UCL (Johnson-1978)	6.981	99% Chebyshev (MVUE) UCL	13.6

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	1.89	**Data appear Gamma Distributed at 5% Significance Level**	
Theta Star	2.287		
MLE of Mean	4.322		
MLE of Standard Deviation	3.144		
nu star	22.68		
Approximate Chi Square Value (.05)	12.85	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0122	95% CLT UCL	6.345
Adjusted Chi Square Value	10.28	95% Jackknife UCL	6.8
		95% Standard Bootstrap UCL	6.221
Anderson-Darling Test Statistic	0.589	95% Bootstrap-t UCL	12.54
Anderson-Darling 5% Critical Value	0.701	95% Hall's Bootstrap UCL	15.46
Kolmogorov-Smirnov Test Statistic	0.284	95% Percentile Bootstrap UCL	6.573
Kolmogorov-Smirnov 5% Critical Value	0.334	95% BCA Bootstrap UCL	6.98
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	9.684
		97.5% Chebyshev(Mean, Sd) UCL	12
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	16.56
95% Approximate Gamma UCL	7.628		
95% Adjusted Gamma UCL	9.533		

Potential UCL to Use		
	Use 95% Approximate Gamma UCL	7.628

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (total phosphorus)

General Statistics

Number of Valid Observations	6	Number of Distinct Observations	5

Raw Statistics		Log-transformed Statistics	
Minimum	0.0031	Minimum of Log Data	-5.776
Maximum	0.0386	Maximum of Log Data	-3.255
Mean	0.0121	Mean of log Data	-4.842
Median	0.00755	SD of log Data	0.977
SD	0.0136		
Std. Error of Mean	0.00554		
Coefficient of Variation	1.118		
Skewness	2.009		

Warning: A sample size of 'n' = 6 may not adequate enough to compute meaningful and reliable test statistics and estimates!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Warning: There are only 6 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set,
the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.737	Shapiro Wilk Test Statistic	0.909
Shapiro Wilk Critical Value	0.788	Shapiro Wilk Critical Value	0.788
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0233	95% H-UCL	0.0744
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0312
95% Adjusted-CLT UCL (Chen-1995)	0.0261	97.5% Chebyshev (MVUE) UCL	0.0398
95% Modified-t UCL (Johnson-1978)	0.024	99% Chebyshev (MVUE) UCL	0.0565

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.763	**Data appear Gamma Distributed at 5% Significance Level**	
Theta Star	0.0159		
MLE of Mean	0.0121		
MLE of Standard Deviation	0.0139		
nu star	9.158		
Approximate Chi Square Value (.05)	3.422	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0122	95% CLT UCL	0.0212
Adjusted Chi Square Value	2.285	95% Jackknife UCL	0.0233
		95% Standard Bootstrap UCL	0.0203
Anderson-Darling Test Statistic	0.431	95% Bootstrap-t UCL	0.0372
Anderson-Darling 5% Critical Value	0.711	95% Hall's Bootstrap UCL	0.0554
Kolmogorov-Smirnov Test Statistic	0.216	95% Percentile Bootstrap UCL	0.0212
Kolmogorov-Smirnov 5% Critical Value	0.339	95% BCA Bootstrap UCL	0.0244
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0363
		97.5% Chebyshev(Mean, Sd) UCL	0.0467
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0672
95% Approximate Gamma UCL	0.0325		
95% Adjusted Gamma UCL	0.0486		

Potential UCL to Use	
Use 95% Approximate Gamma UCL	0.0325

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

General UCL Statistics for Data Sets with Non-Detects

User Selected Options

From File	BTEX_sulf pre-process 03.27.wst
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Result (1/2 DL for NDs) (benzene)

General Statistics

Number of Valid Observations	56	Number of Distinct Observations	31

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.000113	Minimum of Log Data	-9.088
Maximum	7.14	Maximum of Log Data	1.966
Mean	0.453	Mean of log Data	-6.582
Median	0.00025	SD of log Data	3.418
SD	1.511		
Coefficient of Variation	3.333		
Skewness	3.803		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.442	Lilliefors Test Statistic	0.274
Lilliefors Critical Value	0.118	Lilliefors Critical Value	0.118
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.791	95% H-UCL	7.509
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.147
95% Adjusted-CLT UCL (Chen-1995)	0.895	97.5% Chebyshev (MVUE) UCL	1.526
95% Modified-t UCL (Johnson-1978)	0.808	99% Chebyshev (MVUE) UCL	2.272

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.139	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	3.251		
MLE of Mean	0.453		
MLE of Standard Deviation	1.214		
nu star	15.62		
Approximate Chi Square Value (.05)	7.694	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0457	95% CLT UCL	0.785
Adjusted Chi Square Value	7.547	95% Jackknife UCL	0.791
		95% Standard Bootstrap UCL	0.783
Anderson-Darling Test Statistic	10.12	95% Bootstrap-t UCL	1.17
Anderson-Darling 5% Critical Value	0.955	95% Hall's Bootstrap UCL	0.778
Kolmogorov-Smirnov Test Statistic	0.34	95% Percentile Bootstrap UCL	0.81
Kolmogorov-Smirnov 5% Critical Value	0.134	95% BCA Bootstrap UCL	0.924
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1.334
		97.5% Chebyshev(Mean, Sd) UCL	1.714
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	2.463
95% Approximate Gamma UCL	0.92		
95% Adjusted Gamma UCL	0.938		

Potential UCL to Use	
Use 97.5% Chebyshev (Mean, Sd) UCL	1.714

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (ethylbenzene)

General Statistics

Number of Valid Observations	56	Number of Distinct Observations	21

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0000877	Minimum of Log Data	-9.342
Maximum	1.24	Maximum of Log Data	0.215
Mean	0.0573	Mean of log Data	-6.757
Median	0.000375	SD of log Data	2.457
SD	0.211		
Coefficient of Variation	3.687		
Skewness	4.663		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.436	Lilliefors Test Statistic	0.277
Lilliefors Critical Value	0.118	Lilliefors Critical Value	0.118
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.105	95% H-UCL	0.107
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.064
95% Adjusted-CLT UCL (Chen-1995)	0.123	97.5% Chebyshev (MVUE) UCL	0.0833
95% Modified-t UCL (Johnson-1978)	0.108	99% Chebyshev (MVUE) UCL	0.121

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.192	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.0573		
MLE of Standard Deviation	0.131		
nu star	21.5		
Approximate Chi Square Value (.05)	11.96	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0457	95% CLT UCL	0.104
Adjusted Chi Square Value	11.78	95% Jackknife UCL	0.105
		95% Standard Bootstrap UCL	0.104
Anderson-Darling Test Statistic	10.15	95% Bootstrap-t UCL	0.208
Anderson-Darling 5% Critical Value	0.916	95% Hall's Bootstrap UCL	0.275
Kolmogorov-Smirnov Test Statistic	0.364	95% Percentile Bootstrap UCL	0.108
Kolmogorov-Smirnov 5% Critical Value	0.132	95% BCA Bootstrap UCL	0.126
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.18
		97.5% Chebyshev(Mean, Sd) UCL	0.234
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.338
95% Approximate Gamma UCL	0.103		
95% Adjusted Gamma UCL	0.105		

Potential UCL to Use			
		Use 95% Chebyshev (Mean, Sd) UCL	0.18

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (m,p-xylene)

General Statistics

Number of Valid Observations	56	Number of Distinct Observations	22

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.00062	Minimum of Log Data	-7.386
Maximum	4.47	Maximum of Log Data	1.497
Mean	0.342	Mean of log Data	-5.579
Median	0.001	SD of log Data	2.892
SD	1.004		
Coefficient of Variation	2.936		
Skewness	3.244		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.434	Lilliefors Test Statistic	0.362
Lilliefors Critical Value	0.118	Lilliefors Critical Value	0.118
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.567	95% H-UCL	1.885
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.668
95% Adjusted-CLT UCL (Chen-1995)	0.625	97.5% Chebyshev (MVUE) UCL	0.88
95% Modified-t UCL (Johnson-1978)	0.576	99% Chebyshev (MVUE) UCL	1.296

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.171	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	2.004		
MLE of Mean	0.342		
MLE of Standard Deviation	0.828		
nu star	19.11		
Approximate Chi Square Value (.05)	10.2	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0457	95% CLT UCL	0.563
Adjusted Chi Square Value	10.03	95% Jackknife UCL	0.567
		95% Standard Bootstrap UCL	0.561
Anderson-Darling Test Statistic	10.93	95% Bootstrap-t UCL	0.696
Anderson-Darling 5% Critical Value	0.932	95% Hall's Bootstrap UCL	0.556
Kolmogorov-Smirnov Test Statistic	0.402	95% Percentile Bootstrap UCL	0.58
Kolmogorov-Smirnov 5% Critical Value	0.133	95% BCA Bootstrap UCL	0.641
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.927
		97.5% Chebyshev(Mean, Sd) UCL	1.18
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.678
95% Approximate Gamma UCL	0.641		
95% Adjusted Gamma UCL	0.652		

Potential UCL to Use	
Use 97.5% Chebyshev (Mean, Sd) UCL	1.18

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (o-xylene)

General Statistics

Number of Valid Observations	56	Number of Distinct Observations	20

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.00031	Minimum of Log Data	-8.079
Maximum	1.92	Maximum of Log Data	0.652
Mean	0.0841	Mean of log Data	-6.581
Median	0.00032	SD of log Data	2.444
SD	0.331		
Coefficient of Variation	3.941		
Skewness	4.817		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.427	Lilliefors Test Statistic	0.305
Lilliefors Critical Value	0.118	Lilliefors Critical Value	0.118
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.158	95% H-UCL	0.121
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0739
95% Adjusted-CLT UCL (Chen-1995)	0.187	97.5% Chebyshev (MVUE) UCL	0.096
95% Modified-t UCL (Johnson-1978)	0.163	99% Chebyshev (MVUE) UCL	0.139

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.184	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.457		
MLE of Mean	0.0841		
MLE of Standard Deviation	0.196		
nu star	20.62		
Approximate Chi Square Value (.05)	11.31	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0457	95% CLT UCL	0.157
Adjusted Chi Square Value	11.13	95% Jackknife UCL	0.158
		95% Standard Bootstrap UCL	0.156
Anderson-Darling Test Statistic	11.6	95% Bootstrap-t UCL	0.39
Anderson-Darling 5% Critical Value	0.922	95% Hall's Bootstrap UCL	0.458
Kolmogorov-Smirnov Test Statistic	0.378	95% Percentile Bootstrap UCL	0.164
Kolmogorov-Smirnov 5% Critical Value	0.133	95% BCA Bootstrap UCL	0.199
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.277
		97.5% Chebyshev(Mean, Sd) UCL	0.36
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.524
95% Approximate Gamma UCL	0.153		
95% Adjusted Gamma UCL	0.156		

Potential UCL to Use			
		Use 95% Chebyshev (Mean, Sd) UCL	0.277

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (sulfolane)

General Statistics

Number of Valid Observations	78	Number of Distinct Observations	45

Raw Statistics		Log-transformed Statistics	
Minimum	0.0031	Minimum of Log Data	-5.776
Maximum	10.4	Maximum of Log Data	2.342
Mean	0.243	Mean of log Data	-4.031
Median	0.00513	SD of log Data	2.042
SD	1.197		
Coefficient of Variation	4.936		
Skewness	8.176		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.421	Lilliefors Test Statistic	0.241
Lilliefors Critical Value	0.1	Lilliefors Critical Value	0.1
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.468	95% H-UCL	0.322
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.339
95% Adjusted-CLT UCL (Chen-1995)	0.6	97.5% Chebyshev (MVUE) UCL	0.429
95% Modified-t UCL (Johnson-1978)	0.489	99% Chebyshev (MVUE) UCL	0.605

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.267	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.909		
MLE of Mean	0.243		
MLE of Standard Deviation	0.47		
nu star	41.62		
Approximate Chi Square Value (.05)	27.83	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0469	95% CLT UCL	0.466
Adjusted Chi Square Value	27.62	95% Jackknife UCL	0.468
		95% Standard Bootstrap UCL	0.471
Anderson-Darling Test Statistic	9.185	95% Bootstrap-t UCL	1.448
Anderson-Darling 5% Critical Value	0.879	95% Hall's Bootstrap UCL	1.211
Kolmogorov-Smirnov Test Statistic	0.241	95% Percentile Bootstrap UCL	0.495
Kolmogorov-Smirnov 5% Critical Value	0.11	95% BCA Bootstrap UCL	0.674
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.833
		97.5% Chebyshev(Mean, Sd) UCL	1.089
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.591
95% Approximate Gamma UCL	0.363		
95% Adjusted Gamma UCL	0.365		

Potential UCL to Use		
	Use 95% Chebyshev (Mean, Sd) UCL	0.833

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (toluene)

General Statistics

Number of Valid Observations	56	Number of Distinct Observations	17

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.000133	Minimum of Log Data	-8.925
Maximum	12.3	Maximum of Log Data	2.51
Mean	0.342	Mean of log Data	-7.213
Median	0.00031	SD of log Data	2.148
SD	1.863		
Coefficient of Variation	5.439		
Skewness	5.764		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.531	Lilliefors Test Statistic	0.286
Lilliefors Critical Value	0.118	Lilliefors Critical Value	0.118
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.759	95% H-UCL	0.0234
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.019
95% Adjusted-CLT UCL (Chen-1995)	0.957	97.5% Chebyshev (MVUE) UCL	0.0244
95% Modified-t UCL (Johnson-1978)	0.791	99% Chebyshev (MVUE) UCL	0.035

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.133	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	2.574		
MLE of Mean	0.342		
MLE of Standard Deviation	0.939		
nu star	14.9		
Approximate Chi Square Value (.05)	7.193	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0457	95% CLT UCL	0.752
Adjusted Chi Square Value	7.051	95% Jackknife UCL	0.759
		95% Standard Bootstrap UCL	0.75
Anderson-Darling Test Statistic	17.47	95% Bootstrap-t UCL	162.9
Anderson-Darling 5% Critical Value	0.96	95% Hall's Bootstrap UCL	150.2
Kolmogorov-Smirnov Test Statistic	0.467	95% Percentile Bootstrap UCL	0.782
Kolmogorov-Smirnov 5% Critical Value	0.134	95% BCA Bootstrap UCL	1.099
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1.427
		97.5% Chebyshev(Mean, Sd) UCL	1.897
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	2.819
95% Approximate Gamma UCL	0.709		
95% Adjusted Gamma UCL	0.724		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	1.427

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (xylenes (total))

General Statistics

Number of Valid Observations	56	Number of Distinct Observations	25

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.000182	Minimum of Log Data	-8.612
Maximum	6.39	Maximum of Log Data	1.855
Mean	0.428	Mean of log Data	-5.496
Median	0.001	SD of log Data	2.99
SD	1.298		
Coefficient of Variation	3.036		
Skewness	3.521		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.43	Lilliefors Test Statistic	0.365
Lilliefors Critical Value	0.118	Lilliefors Critical Value	0.118
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.718	95% H-UCL	3.095
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.959
95% Adjusted-CLT UCL (Chen-1995)	0.8	97.5% Chebyshev (MVUE) UCL	1.265
95% Modified-t UCL (Johnson-1978)	0.732	99% Chebyshev (MVUE) UCL	1.868

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.167	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	2.568		
MLE of Mean	0.428		
MLE of Standard Deviation	1.048		
nu star	18.65		
Approximate Chi Square Value (.05)	9.862	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0457	95% CLT UCL	0.713
Adjusted Chi Square Value	9.692	95% Jackknife UCL	0.718
		95% Standard Bootstrap UCL	0.709
Anderson-Darling Test Statistic	10.3	95% Bootstrap-t UCL	0.926
Anderson-Darling 5% Critical Value	0.935	95% Hall's Bootstrap UCL	0.727
Kolmogorov-Smirnov Test Statistic	0.404	95% Percentile Bootstrap UCL	0.722
Kolmogorov-Smirnov 5% Critical Value	0.133	95% BCA Bootstrap UCL	0.831
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1.184
		97.5% Chebyshev(Mean, Sd) UCL	1.511
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	2.154
95% Approximate Gamma UCL	0.809		
95% Adjusted Gamma UCL	0.823		

Potential UCL to Use			
		Use 97.5% Chebyshev (Mean, Sd) UCL	1.511

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

General UCL Statistics for Data Sets with Non-Detects

User Selected Options

From File	MB_0-2 All Transposed.wst
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Result (1/2 DL for NDs) (1,1-dichloroethylene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	23

Raw Statistics		Log-transformed Statistics	
Minimum	0.00505	Minimum of Log Data	-5.288
Maximum	0.0158	Maximum of Log Data	-4.148
Mean	0.00916	Mean of log Data	-4.762
Median	0.00753	SD of log Data	0.375
SD	0.00356		
Coefficient of Variation	0.389		
Skewness	0.666		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.868	Shapiro Wilk Test Statistic	0.901
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0104	95% H-UCL	0.0105
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0121
95% Adjusted-CLT UCL (Chen-1995)	0.0104	97.5% Chebyshev (MVUE) UCL	0.0134
95% Modified-t UCL (Johnson-1978)	0.0104	99% Chebyshev (MVUE) UCL	0.016

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	6.556	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0014		
MLE of Mean	0.00916		
MLE of Standard Deviation	0.00358		
nu star	340.9		
Approximate Chi Square Value (.05)	299.1	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.0103
Adjusted Chi Square Value	296.5	95% Jackknife UCL	0.0104
		95% Standard Bootstrap UCL	0.0103
Anderson-Darling Test Statistic	1.09	95% Bootstrap-t UCL	0.0105
Anderson-Darling 5% Critical Value	0.745	95% Hall's Bootstrap UCL	0.0104
Kolmogorov-Smirnov Test Statistic	0.175	95% Percentile Bootstrap UCL	0.0103
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL	0.0104
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0122
		97.5% Chebyshev(Mean, Sd) UCL	0.0135
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0161
95% Approximate Gamma UCL	0.0104		
95% Adjusted Gamma UCL	0.0105		

Potential UCL to Use	
Use 95% Student's-t UCL	0.0104
or 95% Modified-t UCL	0.0104

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (1,2,4-trimethylbenzene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	24

Raw Statistics		Log-transformed Statistics	
Minimum	0.00975	Minimum of Log Data	-4.63
Maximum	0.0315	Maximum of Log Data	-3.459
Mean	0.0184	Mean of log Data	-4.069
Median	0.0153	SD of log Data	0.389
SD	0.00724		
Coefficient of Variation	0.394		
Skewness	0.54		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.88	Shapiro Wilk Test Statistic	0.906
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.0208	95% H-UCL	0.0213
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0246
95% Adjusted-CLT UCL (Chen-1995)	0.0209	97.5% Chebyshev (MVUE) UCL	0.0273
95% Modified-t UCL (Johnson-1978)	0.0208	99% Chebyshev (MVUE) UCL	0.0327

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	6.211	**Data Follow Appr. Gamma Distribution at 5% Significance Level**	
Theta Star	0.00296		
MLE of Mean	0.0184		
MLE of Standard Deviation	0.00738		
nu star	323		
Approximate Chi Square Value (.05)	282.4	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.0207
Adjusted Chi Square Value	279.9	95% Jackknife UCL	0.0208
		95% Standard Bootstrap UCL	0.0207
Anderson-Darling Test Statistic	0.985	95% Bootstrap-t UCL	0.0211
Anderson-Darling 5% Critical Value	0.745	95% Hall's Bootstrap UCL	0.0208
Kolmogorov-Smirnov Test Statistic	0.171	95% Percentile Bootstrap UCL	0.0209
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL	0.021
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0246
		97.5% Chebyshev(Mean, Sd) UCL	0.0273
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0325
95% Approximate Gamma UCL	0.021		
95% Adjusted Gamma UCL	0.0212		

Potential UCL to Use		
	Use 95% Approximate Gamma UCL	0.021

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (1,2-dichlorobenzene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.413
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.53
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.38
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.717
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (1,3,5-trimethylbenzene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	23

Raw Statistics		Log-transformed Statistics	
Minimum	0.00505	Minimum of Log Data	-5.288
Maximum	0.0223	Maximum of Log Data	-3.803
Mean	0.0104	Mean of log Data	-4.664
Median	0.00898	SD of log Data	0.438
SD	0.00473		
Coefficient of Variation	0.456		
Skewness	0.893		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.893	Shapiro Wilk Test Statistic	0.933
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.0119	95% H-UCL	0.0123
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0143
95% Adjusted-CLT UCL (Chen-1995)	0.0121	97.5% Chebyshev (MVUE) UCL	0.0161
95% Modified-t UCL (Johnson-1978)	0.012	99% Chebyshev (MVUE) UCL	0.0195

Gamma Distribution Test		Data Distribution
k star (bias corrected)	4.864	**Data appear Gamma Distributed at 5% Significance Level**
Theta Star	0.00213	
MLE of Mean	0.0104	
MLE of Standard Deviation	0.0047	
nu star	252.9	
Approximate Chi Square Value (.05)	217.1	**Nonparametric Statistics**
Adjusted Level of Significance	0.0398	95% CLT UCL 0.0119
Adjusted Chi Square Value	214.9	95% Jackknife UCL 0.0119
		95% Standard Bootstrap UCL 0.0118
Anderson-Darling Test Statistic	0.734	95% Bootstrap-t UCL 0.0121
Anderson-Darling 5% Critical Value	0.746	95% Hall's Bootstrap UCL 0.012
Kolmogorov-Smirnov Test Statistic	0.163	95% Percentile Bootstrap UCL 0.0119
Kolmogorov-Smirnov 5% Critical Value	0.172	95% BCA Bootstrap UCL 0.012
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0144
		97.5% Chebyshev(Mean, Sd) UCL 0.0161
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0196
95% Approximate Gamma UCL	0.0121	
95% Adjusted Gamma UCL	0.0122	

Potential UCL to Use	
Use 95% Approximate Gamma UCL	0.0121

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (1,3-dichlorobenzene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.416
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.37
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.719
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.592
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (1-methylnaphthalene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	69

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	3.21	Maximum of Log Data	1.166
Mean	0.082	Mean of log Data	-5.075
Median	0.00332	SD of log Data	1.733
SD	0.374		
Coefficient of Variation	4.556		
Skewness	6.853		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.432	Lilliefors Test Statistic	0.207
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.143	95% H-UCL	0.0467
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0568
95% Adjusted-CLT UCL (Chen-1995)	0.169	97.5% Chebyshev (MVUE) UCL	0.0697
95% Modified-t UCL (Johnson-1978)	0.147	99% Chebyshev (MVUE) UCL	0.095

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.271	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.303		
MLE of Mean	0.082		
MLE of Standard Deviation	0.158		
nu star	56.32		
Approximate Chi Square Value (.05)	40.07	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0477	95% CLT UCL	0.142
Adjusted Chi Square Value	39.88	95% Jackknife UCL	0.143
		95% Standard Bootstrap UCL	0.143
Anderson-Darling Test Statistic	17.91	95% Bootstrap-t UCL	0.271
Anderson-Darling 5% Critical Value	0.88	95% Hall's Bootstrap UCL	0.342
Kolmogorov-Smirnov Test Statistic	0.338	95% Percentile Bootstrap UCL	0.155
Kolmogorov-Smirnov 5% Critical Value	0.0965	95% BCA Bootstrap UCL	0.173
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.242
		97.5% Chebyshev(Mean, Sd) UCL	0.311
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.446
95% Approximate Gamma UCL	0.115		
95% Adjusted Gamma UCL	0.116		

Potential UCL to Use		
		Use 95% Chebyshev (Mean, Sd) UCL 0.242

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2,4,6-trichlorophenol)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.412
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.91
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.447
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.594
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2,4-dichlorophenol)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.421
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.94
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.409
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.717
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2,4-dimethylphenol)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.413
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.82
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.508
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.594
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2,4-dinitrophenol)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.945	Minimum of Log Data	-0.0566
Maximum	40.7	Maximum of Log Data	3.706
Mean	2.551	Mean of log Data	0.163
Median	0.993	SD of log Data	0.726
SD	7.781		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.278
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	5.157	95% H-UCL	2.104
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	2.531
95% Adjusted-CLT UCL (Chen-1995)	6.691	97.5% Chebyshev (MVUE) UCL	2.971
95% Modified-t UCL (Johnson-1978)	5.412	99% Chebyshev (MVUE) UCL	3.836

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	3.602		
MLE of Mean	2.551		
MLE of Standard Deviation	3.031		
nu star	36.82		
Approximate Chi Square Value (.05)	23.93	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	5.061
Adjusted Chi Square Value	23.24	95% Jackknife UCL	5.157
		95% Standard Bootstrap UCL	5.001
Anderson-Darling Test Statistic	9.147	95% Bootstrap-t UCL	190.1
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	93.68
Kolmogorov-Smirnov Test Statistic	0.528	95% Percentile Bootstrap UCL	5.602
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	7.147
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	9.203
		97.5% Chebyshev(Mean, Sd) UCL	12.08
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	17.73
95% Approximate Gamma UCL	3.925		
95% Adjusted Gamma UCL	4.041		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	9.203

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2,4-dinitrotoluene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.408
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.48
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.62
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.592
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2,6-dinitrotoluene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.419
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.52
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.788
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.594
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2-chlorophenol)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.418
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.66
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.306
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.464
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.593
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2-methylnaphthalene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	72

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	3.66	Maximum of Log Data	1.297
Mean	0.0903	Mean of log Data	-5.072
Median	0.00377	SD of log Data	1.71
SD	0.431		
Coefficient of Variation	4.768		
Skewness	6.808		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.44	Lilliefors Test Statistic	0.204
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.16	95% H-UCL	0.0445
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0543
95% Adjusted-CLT UCL (Chen-1995)	0.19	97.5% Chebyshev (MVUE) UCL	0.0665
95% Modified-t UCL (Johnson-1978)	0.165	99% Chebyshev (MVUE) UCL	0.0904

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.263	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.344		
MLE of Mean	0.0903		
MLE of Standard Deviation	0.176		
nu star	54.64		
Approximate Chi Square Value (.05)	38.65	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0477	95% CLT UCL	0.16
Adjusted Chi Square Value	38.46	95% Jackknife UCL	0.16
		95% Standard Bootstrap UCL	0.161
Anderson-Darling Test Statistic	18.85	95% Bootstrap-t UCL	0.282
Anderson-Darling 5% Critical Value	0.884	95% Hall's Bootstrap UCL	0.379
Kolmogorov-Smirnov Test Statistic	0.335	95% Percentile Bootstrap UCL	0.171
Kolmogorov-Smirnov 5% Critical Value	0.0967	95% BCA Bootstrap UCL	0.202
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.274
		97.5% Chebyshev(Mean, Sd) UCL	0.354
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.511
95% Approximate Gamma UCL	0.128		
95% Adjusted Gamma UCL	0.128		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.274

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2-methylphenol (o-cresol))

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.419
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.52
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.3
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.593
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (3&4-methylphenol (p&m-cresol))

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	23

Raw Statistics		Log-transformed Statistics	
Minimum	0.312	Minimum of Log Data	-1.165
Maximum	13.4	Maximum of Log Data	2.595
Mean	0.841	Mean of log Data	-0.945
Median	0.328	SD of log Data	0.726
SD	2.562		
Coefficient of Variation	3.047		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.278
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	1.699	95% H-UCL	0.694
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.835
95% Adjusted-CLT UCL (Chen-1995)	2.204	97.5% Chebyshev (MVUE) UCL	0.98
95% Modified-t UCL (Johnson-1978)	1.783	99% Chebyshev (MVUE) UCL	1.265

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.709	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	1.185		
MLE of Mean	0.841		
MLE of Standard Deviation	0.998		
nu star	36.88		
Approximate Chi Square Value (.05)	23.98	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	1.667
Adjusted Chi Square Value	23.29	95% Jackknife UCL	1.699
		95% Standard Bootstrap UCL	1.651
Anderson-Darling Test Statistic	9.147	95% Bootstrap-t UCL	62.1
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	30.54
Kolmogorov-Smirnov Test Statistic	0.528	95% Percentile Bootstrap UCL	1.843
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	2.354
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	3.031
		97.5% Chebyshev(Mean, Sd) UCL	3.978
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	5.839
95% Approximate Gamma UCL	1.293		
95% Adjusted Gamma UCL	1.331		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	3.031

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (3,3-dichlorobenzidine)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.415
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.82
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.41
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.593
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (4-chloroaniline)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	20

Raw Statistics		Log-transformed Statistics	
Minimum	0.151	Minimum of Log Data	-1.89
Maximum	6.5	Maximum of Log Data	1.872
Mean	0.407	Mean of log Data	-1.672
Median	0.159	SD of log Data	0.727
SD	1.243		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.824	95% H-UCL	0.336
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.404
95% Adjusted-CLT UCL (Chen-1995)	1.069	97.5% Chebyshev (MVUE) UCL	0.474
95% Modified-t UCL (Johnson-1978)	0.864	99% Chebyshev (MVUE) UCL	0.612

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.575		
MLE of Mean	0.407		
MLE of Standard Deviation	0.484		
nu star	36.8		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.808
Adjusted Chi Square Value	23.23	95% Jackknife UCL	0.824
		95% Standard Bootstrap UCL	0.809
Anderson-Darling Test Statistic	9.143	95% Bootstrap-t UCL	29.9
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	14.68
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.895
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	1.139
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1.47
		97.5% Chebyshev(Mean, Sd) UCL	1.929
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	2.832
95% Approximate Gamma UCL	0.627		
95% Adjusted Gamma UCL	0.645		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	1.47

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (4-isopropyltoluene (p-cymene))

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	23

Raw Statistics		Log-transformed Statistics	
Minimum	0.00505	Minimum of Log Data	-5.288
Maximum	0.0182	Maximum of Log Data	-4.006
Mean	0.0097	Mean of log Data	-4.713
Median	0.00795	SD of log Data	0.4
SD	0.00394		
Coefficient of Variation	0.406		
Skewness	0.598		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.891	Shapiro Wilk Test Statistic	0.913
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.011	95% H-UCL	0.0113
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0131
95% Adjusted-CLT UCL (Chen-1995)	0.0111	97.5% Chebyshev (MVUE) UCL	0.0146
95% Modified-t UCL (Johnson-1978)	0.011	99% Chebyshev (MVUE) UCL	0.0175

Gamma Distribution Test		Data Distribution
k star (bias corrected)	5.878	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.00165	
MLE of Mean	0.0097	
MLE of Standard Deviation	0.004	
nu star	305.7	
Approximate Chi Square Value (.05)	266.2	**Nonparametric Statistics**
Adjusted Level of Significance	0.0398	95% CLT UCL 0.011
Adjusted Chi Square Value	263.7	95% Jackknife UCL 0.011
		95% Standard Bootstrap UCL 0.011
Anderson-Darling Test Statistic	0.977	95% Bootstrap-t UCL 0.0111
Anderson-Darling 5% Critical Value	0.746	95% Hall's Bootstrap UCL 0.0111
Kolmogorov-Smirnov Test Statistic	0.176	95% Percentile Bootstrap UCL 0.011
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL 0.0111
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0131
		97.5% Chebyshev(Mean, Sd) UCL 0.0145
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0174
95% Approximate Gamma UCL	0.0111	
95% Adjusted Gamma UCL	0.0112	

Potential UCL to Use	
Use 95% Student's-t UCL	0.011
or 95% Modified-t UCL	0.011

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (acenaphthene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	53

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.097	Maximum of Log Data	-2.333
Mean	0.00725	Mean of log Data	-5.599
Median	0.00183	SD of log Data	1.029
SD	0.013		
Coefficient of Variation	1.796		
Skewness	4.614		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.338	Lilliefors Test Statistic	0.282
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.00937	95% H-UCL	0.00788
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00956
95% Adjusted-CLT UCL (Chen-1995)	0.00997	97.5% Chebyshev (MVUE) UCL	0.011
95% Modified-t UCL (Johnson-1978)	0.00947	99% Chebyshev (MVUE) UCL	0.0138

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.854	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.00849		
MLE of Mean	0.00725		
MLE of Standard Deviation	0.00785		
nu star	177.7		
Approximate Chi Square Value (.05)	147.8	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0477	95% CLT UCL	0.00935
Adjusted Chi Square Value	147.5	95% Jackknife UCL	0.00937
		95% Standard Bootstrap UCL	0.00936
Anderson-Darling Test Statistic	10.15	95% Bootstrap-t UCL	0.0106
Anderson-Darling 5% Critical Value	0.789	95% Hall's Bootstrap UCL	0.0108
Kolmogorov-Smirnov Test Statistic	0.281	95% Percentile Bootstrap UCL	0.00932
Kolmogorov-Smirnov 5% Critical Value	0.0915	95% BCA Bootstrap UCL	0.01
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0128
		97.5% Chebyshev(Mean, Sd) UCL	0.0152
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.02
95% Approximate Gamma UCL	0.00872		
95% Adjusted Gamma UCL	0.00874		

Potential UCL to Use		
Use 95% Chebyshev (Mean, Sd) UCL	0.0128	

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (acenaphthylene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	54

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.097	Maximum of Log Data	-2.333
Mean	0.00728	Mean of log Data	-5.596
Median	0.00183	SD of log Data	1.031
SD	0.013		
Coefficient of Variation	1.791		
Skewness	4.605		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.33	Lilliefors Test Statistic	0.282
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.0094	95% H-UCL	0.00793
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00962
95% Adjusted-CLT UCL (Chen-1995)	0.01	97.5% Chebyshev (MVUE) UCL	0.0111
95% Modified-t UCL (Johnson-1978)	0.00949	99% Chebyshev (MVUE) UCL	0.0139

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.853	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.00853	
MLE of Mean	0.00728	
MLE of Standard Deviation	0.00788	
nu star	177.5	
Approximate Chi Square Value (.05)	147.7	**Nonparametric Statistics**
Adjusted Level of Significance	0.0477	95% CLT UCL 0.00938
Adjusted Chi Square Value	147.3	95% Jackknife UCL 0.0094
		95% Standard Bootstrap UCL 0.00935
Anderson-Darling Test Statistic	10.05	95% Bootstrap-t UCL 0.0108
Anderson-Darling 5% Critical Value	0.789	95% Hall's Bootstrap UCL 0.0108
Kolmogorov-Smirnov Test Statistic	0.281	95% Percentile Bootstrap UCL 0.0095
Kolmogorov-Smirnov 5% Critical Value	0.0915	95% BCA Bootstrap UCL 0.0102
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0128
		97.5% Chebyshev(Mean, Sd) UCL 0.0153
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.02
95% Approximate Gamma UCL	0.00875	
95% Adjusted Gamma UCL	0.00877	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0128

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (anthracene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	56

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.097	Maximum of Log Data	-2.333
Mean	0.00753	Mean of log Data	-5.564
Median	0.00188	SD of log Data	1.041
SD	0.0132		
Coefficient of Variation	1.751		
Skewness	4.43		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.338	Lilliefors Test Statistic	0.271
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.00968	95% H-UCL	0.0083
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0101
95% Adjusted-CLT UCL (Chen-1995)	0.0103	97.5% Chebyshev (MVUE) UCL	0.0116
95% Modified-t UCL (Johnson-1978)	0.00977	99% Chebyshev (MVUE) UCL	0.0146

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.85	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.00886	
MLE of Mean	0.00753	
MLE of Standard Deviation	0.00817	
nu star	176.9	
Approximate Chi Square Value (.05)	147.1	**Nonparametric Statistics**
Adjusted Level of Significance	0.0477	95% CLT UCL 0.00966
Adjusted Chi Square Value	146.7	95% Jackknife UCL 0.00968
		95% Standard Bootstrap UCL 0.00961
Anderson-Darling Test Statistic	9.585	95% Bootstrap-t UCL 0.011
Anderson-Darling 5% Critical Value	0.789	95% Hall's Bootstrap UCL 0.011
Kolmogorov-Smirnov Test Statistic	0.268	95% Percentile Bootstrap UCL 0.00981
Kolmogorov-Smirnov 5% Critical Value	0.0915	95% BCA Bootstrap UCL 0.0103
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0132
		97.5% Chebyshev(Mean, Sd) UCL 0.0156
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0204
95% Approximate Gamma UCL	0.00906	
95% Adjusted Gamma UCL	0.00908	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0132

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (antimony)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	26

Raw Statistics		Log-transformed Statistics	
Minimum	0.0524	Minimum of Log Data	-2.949
Maximum	0.227	Maximum of Log Data	-1.483
Mean	0.109	Mean of log Data	-2.29
Median	0.0958	SD of log Data	0.389
SD	0.0445		
Coefficient of Variation	0.408		
Skewness	0.949		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.908	Shapiro Wilk Test Statistic	0.963
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.124	95% H-UCL	0.126
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.146
95% Adjusted-CLT UCL (Chen-1995)	0.125	97.5% Chebyshev (MVUE) UCL	0.162
95% Modified-t UCL (Johnson-1978)	0.124	99% Chebyshev (MVUE) UCL	0.194

Gamma Distribution Test		Data Distribution
k star (bias corrected)	6.116	**Data appear Gamma Distributed at 5% Significance Level**
Theta Star	0.0178	
MLE of Mean	0.109	
MLE of Standard Deviation	0.0441	
nu star	318	
Approximate Chi Square Value (.05)	277.7	**Nonparametric Statistics**
Adjusted Level of Significance	0.0398	95% CLT UCL 0.123
Adjusted Chi Square Value	275.2	95% Jackknife UCL 0.124
		95% Standard Bootstrap UCL 0.123
Anderson-Darling Test Statistic	0.497	95% Bootstrap-t UCL 0.127
Anderson-Darling 5% Critical Value	0.746	95% Hall's Bootstrap UCL 0.125
Kolmogorov-Smirnov Test Statistic	0.132	95% Percentile Bootstrap UCL 0.123
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL 0.126
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.147
		97.5% Chebyshev(Mean, Sd) UCL 0.164
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.196
95% Approximate Gamma UCL	0.125	
95% Adjusted Gamma UCL	0.126	

Potential UCL to Use	
Use 95% Approximate Gamma UCL	0.125

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (arsenic)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	24

Raw Statistics		Log-transformed Statistics	
Minimum	2.45	Minimum of Log Data	0.896
Maximum	17.6	Maximum of Log Data	2.868
Mean	6.386	Mean of log Data	1.732
Median	5.095	SD of log Data	0.49
SD	3.501		
Coefficient of Variation	0.548		
Skewness	1.54		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.85	Shapiro Wilk Test Statistic	0.954
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	7.559	95% H-UCL	7.72
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	9.104
95% Adjusted-CLT UCL (Chen-1995)	7.737	97.5% Chebyshev (MVUE) UCL	10.3
95% Modified-t UCL (Johnson-1978)	7.594	99% Chebyshev (MVUE) UCL	12.65

Gamma Distribution Test		Data Distribution
k star (bias corrected)	3.787	**Data appear Gamma Distributed at 5% Significance Level**
Theta Star	1.687	
MLE of Mean	6.386	
MLE of Standard Deviation	3.282	
nu star	196.9	
Approximate Chi Square Value (.05)	165.4	**Nonparametric Statistics**
Adjusted Level of Significance	0.0398	95% CLT UCL 7.516
Adjusted Chi Square Value	163.5	95% Jackknife UCL 7.559
		95% Standard Bootstrap UCL 7.503
Anderson-Darling Test Statistic	0.684	95% Bootstrap-t UCL 7.853
Anderson-Darling 5% Critical Value	0.747	95% Hall's Bootstrap UCL 8.163
Kolmogorov-Smirnov Test Statistic	0.154	95% Percentile Bootstrap UCL 7.548
Kolmogorov-Smirnov 5% Critical Value	0.172	95% BCA Bootstrap UCL 7.848
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 9.379
		97.5% Chebyshev(Mean, Sd) UCL 10.67
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 13.22
95% Approximate Gamma UCL	7.601	
95% Adjusted Gamma UCL	7.689	

Potential UCL to Use	
Use 95% Approximate Gamma UCL	7.601

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (bap teq)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	68

Raw Statistics		Log-transformed Statistics	
Minimum	0.00351	Minimum of Log Data	-5.651
Maximum	0.225	Maximum of Log Data	-1.492
Mean	0.0178	Mean of log Data	-4.753
Median	0.00421	SD of log Data	1.064
SD	0.0324		
Coefficient of Variation	1.815		
Skewness	4.112		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.345	Lilliefors Test Statistic	0.287
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0231	95% H-UCL	0.0193
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0234
95% Adjusted-CLT UCL (Chen-1995)	0.0244	97.5% Chebyshev (MVUE) UCL	0.0271
95% Modified-t UCL (Johnson-1978)	0.0233	99% Chebyshev (MVUE) UCL	0.0342

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.797	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0224		
MLE of Mean	0.0178		
MLE of Standard Deviation	0.02		
nu star	165.8		
Approximate Chi Square Value (.05)	137.1	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0477	95% CLT UCL	0.0231
Adjusted Chi Square Value	136.7	95% Jackknife UCL	0.0231
		95% Standard Bootstrap UCL	0.0231
Anderson-Darling Test Statistic	10.72	95% Bootstrap-t UCL	0.0253
Anderson-Darling 5% Critical Value	0.792	95% Hall's Bootstrap UCL	0.0256
Kolmogorov-Smirnov Test Statistic	0.287	95% Percentile Bootstrap UCL	0.0234
Kolmogorov-Smirnov 5% Critical Value	0.0917	95% BCA Bootstrap UCL	0.025
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0317
		97.5% Chebyshev(Mean, Sd) UCL	0.0377
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0494
95% Approximate Gamma UCL	0.0216		
95% Adjusted Gamma UCL	0.0216		

Potential UCL to Use		
Use 95% Chebyshev (Mean, Sd) UCL	0.0317	

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	92

Raw Statistics		Log-transformed Statistics	
Minimum	0.00241	Minimum of Log Data	-6.028
Maximum	0.597	Maximum of Log Data	-0.516
Mean	0.02	Mean of log Data	-5.099
Median	0.00464	SD of log Data	1.011
SD	0.0719		
Coefficient of Variation	3.594		
Skewness	6.262		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.441	Lilliefors Test Statistic	0.243
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.0317	95% H-UCL	0.0127
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0153
95% Adjusted-CLT UCL (Chen-1995)	0.0363	97.5% Chebyshev (MVUE) UCL	0.0176
95% Modified-t UCL (Johnson-1978)	0.0325	99% Chebyshev (MVUE) UCL	0.0221

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.521	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0384	
MLE of Mean	0.02	
MLE of Standard Deviation	0.0277	
nu star	108.4	
Approximate Chi Square Value (.05)	85.33	**Nonparametric Statistics**
Adjusted Level of Significance	0.0477	95% CLT UCL 0.0316
Adjusted Chi Square Value	85.05	95% Jackknife UCL 0.0317
		95% Standard Bootstrap UCL 0.0313
Anderson-Darling Test Statistic	21.86	95% Bootstrap-t UCL 0.0494
Anderson-Darling 5% Critical Value	0.816	95% Hall's Bootstrap UCL 0.036
Kolmogorov-Smirnov Test Statistic	0.391	95% Percentile Bootstrap UCL 0.0322
Kolmogorov-Smirnov 5% Critical Value	0.0933	95% BCA Bootstrap UCL 0.0376
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0508
		97.5% Chebyshev(Mean, Sd) UCL 0.0641
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0902
95% Approximate Gamma UCL	0.0254	
95% Adjusted Gamma UCL	0.0255	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0508

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzo(a)anthracene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	55

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.097	Maximum of Log Data	-2.333
Mean	0.00777	Mean of log Data	-5.591
Median	0.00182	SD of log Data	1.068
SD	0.0141		
Coefficient of Variation	1.816		
Skewness	4.062		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.346	Lilliefors Test Statistic	0.286
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.0101	95% H-UCL	0.00839
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0102
95% Adjusted-CLT UCL (Chen-1995)	0.0106	97.5% Chebyshev (MVUE) UCL	0.0118
95% Modified-t UCL (Johnson-1978)	0.0102	99% Chebyshev (MVUE) UCL	0.0149

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.792	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.00982	
MLE of Mean	0.00777	
MLE of Standard Deviation	0.00873	
nu star	164.6	
Approximate Chi Square Value (.05)	136	**Nonparametric Statistics**
Adjusted Level of Significance	0.0477	95% CLT UCL 0.01
Adjusted Chi Square Value	135.6	95% Jackknife UCL 0.0101
		95% Standard Bootstrap UCL 0.01
Anderson-Darling Test Statistic	10.78	95% Bootstrap-t UCL 0.011
Anderson-Darling 5% Critical Value	0.792	95% Hall's Bootstrap UCL 0.011
Kolmogorov-Smirnov Test Statistic	0.287	95% Percentile Bootstrap UCL 0.0103
Kolmogorov-Smirnov 5% Critical Value	0.0917	95% BCA Bootstrap UCL 0.0107
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0138
		97.5% Chebyshev(Mean, Sd) UCL 0.0164
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0215
95% Approximate Gamma UCL	0.00941	
95% Adjusted Gamma UCL	0.00943	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0138

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzo(a)pyrene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	55

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.097	Maximum of Log Data	-2.333
Mean	0.00814	Mean of log Data	-5.584
Median	0.00182	SD of log Data	1.084
SD	0.0156		
Coefficient of Variation	1.919		
Skewness	4.131		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.358	Lilliefors Test Statistic	0.285
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0107	95% H-UCL	0.00863
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0105
95% Adjusted-CLT UCL (Chen-1995)	0.0113	97.5% Chebyshev (MVUE) UCL	0.0122
95% Modified-t UCL (Johnson-1978)	0.0108	99% Chebyshev (MVUE) UCL	0.0154

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.755	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0108		
MLE of Mean	0.00814		
MLE of Standard Deviation	0.00937		
nu star	157.1		
Approximate Chi Square Value (.05)	129.1	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0477	95% CLT UCL	0.0107
Adjusted Chi Square Value	128.7	95% Jackknife UCL	0.0107
		95% Standard Bootstrap UCL	0.0106
Anderson-Darling Test Statistic	11.08	95% Bootstrap-t UCL	0.0118
Anderson-Darling 5% Critical Value	0.794	95% Hall's Bootstrap UCL	0.0119
Kolmogorov-Smirnov Test Statistic	0.285	95% Percentile Bootstrap UCL	0.0108
Kolmogorov-Smirnov 5% Critical Value	0.0918	95% BCA Bootstrap UCL	0.0116
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0148
		97.5% Chebyshev(Mean, Sd) UCL	0.0177
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0234
95% Approximate Gamma UCL	0.00991		
95% Adjusted Gamma UCL	0.00994		

Potential UCL to Use		
Use 95% Chebyshev (Mean, Sd) UCL	0.0148	

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzo(b)fluoranthene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	60

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.108	Maximum of Log Data	-2.226
Mean	0.00843	Mean of log Data	-5.556
Median	0.0019	SD of log Data	1.08
SD	0.0166		
Coefficient of Variation	1.971		
Skewness	4.288		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.365	Lilliefors Test Statistic	0.254
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.0111	95% H-UCL	0.00883
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0108
95% Adjusted-CLT UCL (Chen-1995)	0.0118	97.5% Chebyshev (MVUE) UCL	0.0124
95% Modified-t UCL (Johnson-1978)	0.0112	99% Chebyshev (MVUE) UCL	0.0158

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.75	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0112	
MLE of Mean	0.00843	
MLE of Standard Deviation	0.00974	
nu star	155.9	
Approximate Chi Square Value (.05)	128	**Nonparametric Statistics**
Adjusted Level of Significance	0.0477	95% CLT UCL 0.0111
Adjusted Chi Square Value	127.7	95% Jackknife UCL 0.0111
		95% Standard Bootstrap UCL 0.0111
Anderson-Darling Test Statistic	10.59	95% Bootstrap-t UCL 0.013
Anderson-Darling 5% Critical Value	0.794	95% Hall's Bootstrap UCL 0.0126
Kolmogorov-Smirnov Test Statistic	0.251	95% Percentile Bootstrap UCL 0.0113
Kolmogorov-Smirnov 5% Critical Value	0.0918	95% BCA Bootstrap UCL 0.0121
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0155
		97.5% Chebyshev(Mean, Sd) UCL 0.0186
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0246
95% Approximate Gamma UCL	0.0103	
95% Adjusted Gamma UCL	0.0103	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0155

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzo(g,h,i)perylene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	63

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.186	Maximum of Log Data	-1.682
Mean	0.0118	Mean of log Data	-5.443
Median	0.00194	SD of log Data	1.239
SD	0.0256		
Coefficient of Variation	2.158		
Skewness	4.42		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.358	Lilliefors Test Statistic	0.248
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.016	95% H-UCL	0.0125
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0155
95% Adjusted-CLT UCL (Chen-1995)	0.0171	97.5% Chebyshev (MVUE) UCL	0.0182
95% Modified-t UCL (Johnson-1978)	0.0162	99% Chebyshev (MVUE) UCL	0.0235

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.601	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0197		
MLE of Mean	0.0118		
MLE of Standard Deviation	0.0153		
nu star	124.9		
Approximate Chi Square Value (.05)	100.1	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0477	95% CLT UCL	0.016
Adjusted Chi Square Value	99.8	95% Jackknife UCL	0.016
		95% Standard Bootstrap UCL	0.0159
Anderson-Darling Test Statistic	10.87	95% Bootstrap-t UCL	0.0179
Anderson-Darling 5% Critical Value	0.808	95% Hall's Bootstrap UCL	0.0185
Kolmogorov-Smirnov Test Statistic	0.245	95% Percentile Bootstrap UCL	0.0162
Kolmogorov-Smirnov 5% Critical Value	0.0928	95% BCA Bootstrap UCL	0.0174
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0228
		97.5% Chebyshev(Mean, Sd) UCL	0.0275
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0368
95% Approximate Gamma UCL	0.0148		
95% Adjusted Gamma UCL	0.0148		

Potential UCL to Use		
Use 95% Chebyshev (Mean, Sd) UCL	0.0228	

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzo(k)fluoranthene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	55

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.097	Maximum of Log Data	-2.333
Mean	0.00747	Mean of log Data	-5.6
Median	0.00182	SD of log Data	1.05
SD	0.0134		
Coefficient of Variation	1.796		
Skewness	4.316		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.336	Lilliefors Test Statistic	0.287
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.00966	95% H-UCL	0.0081
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00984
95% Adjusted-CLT UCL (Chen-1995)	0.0102	97.5% Chebyshev (MVUE) UCL	0.0113
95% Modified-t UCL (Johnson-1978)	0.00975	99% Chebyshev (MVUE) UCL	0.0143

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.821	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.00911	
MLE of Mean	0.00747	
MLE of Standard Deviation	0.00825	
nu star	170.7	
Approximate Chi Square Value (.05)	141.5	**Nonparametric Statistics**
Adjusted Level of Significance	0.0477	95% CLT UCL 0.00964
Adjusted Chi Square Value	141.1	95% Jackknife UCL 0.00966
		95% Standard Bootstrap UCL 0.00954
Anderson-Darling Test Statistic	10.54	95% Bootstrap-t UCL 0.0107
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 0.0111
Kolmogorov-Smirnov Test Statistic	0.287	95% Percentile Bootstrap UCL 0.00973
Kolmogorov-Smirnov 5% Critical Value	0.0916	95% BCA Bootstrap UCL 0.0107
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0132
		97.5% Chebyshev(Mean, Sd) UCL 0.0157
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0206
95% Approximate Gamma UCL	0.00902	
95% Adjusted Gamma UCL	0.00904	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0132

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (bis(2-chloroethyl)ether)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.409
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.47
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.403
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.593
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (bis(2-ethylhexyl)phthalate)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.42
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.81
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.624
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.592
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (chlorobenzene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	23

Raw Statistics		Log-transformed Statistics	
Minimum	0.00505	Minimum of Log Data	-5.288
Maximum	0.0158	Maximum of Log Data	-4.148
Mean	0.00916	Mean of log Data	-4.762
Median	0.00753	SD of log Data	0.375
SD	0.00356		
Coefficient of Variation	0.389		
Skewness	0.666		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.868	Shapiro Wilk Test Statistic	0.901
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0104	95% H-UCL	0.0105
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0121
95% Adjusted-CLT UCL (Chen-1995)	0.0104	97.5% Chebyshev (MVUE) UCL	0.0134
95% Modified-t UCL (Johnson-1978)	0.0104	99% Chebyshev (MVUE) UCL	0.016

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	6.556	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0014		
MLE of Mean	0.00916		
MLE of Standard Deviation	0.00358		
nu star	340.9		
Approximate Chi Square Value (.05)	299.1	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.0103
Adjusted Chi Square Value	296.5	95% Jackknife UCL	0.0104
		95% Standard Bootstrap UCL	0.0103
Anderson-Darling Test Statistic	1.09	95% Bootstrap-t UCL	0.0105
Anderson-Darling 5% Critical Value	0.745	95% Hall's Bootstrap UCL	0.0103
Kolmogorov-Smirnov Test Statistic	0.175	95% Percentile Bootstrap UCL	0.0103
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL	0.0105
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0122
		97.5% Chebyshev(Mean, Sd) UCL	0.0135
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0161
95% Approximate Gamma UCL	0.0104		
95% Adjusted Gamma UCL	0.0105		

Potential UCL to Use	
Use 95% Student's-t UCL	0.0104
or 95% Modified-t UCL	0.0104

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (chromium (total))

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	24

Raw Statistics		Log-transformed Statistics	
Minimum	8.83	Minimum of Log Data	2.178
Maximum	50.9	Maximum of Log Data	3.93
Mean	16.99	Mean of log Data	2.762
Median	14.9	SD of log Data	0.354
SD	8.051		
Coefficient of Variation	0.474		
Skewness	3.167		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.682	Shapiro Wilk Test Statistic	0.908
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	19.69	95% H-UCL	19.21
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	22
95% Adjusted-CLT UCL (Chen-1995)	20.63	97.5% Chebyshev (MVUE) UCL	24.25
95% Modified-t UCL (Johnson-1978)	19.85	99% Chebyshev (MVUE) UCL	28.67

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	6.429	**Data Follow Appr. Gamma Distribution at 5% Significance Level**	
Theta Star	2.643		
MLE of Mean	16.99		
MLE of Standard Deviation	6.701		
nu star	334.3		
Approximate Chi Square Value (.05)	292.9	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	19.59
Adjusted Chi Square Value	290.4	95% Jackknife UCL	19.69
		95% Standard Bootstrap UCL	19.51
Anderson-Darling Test Statistic	0.986	95% Bootstrap-t UCL	21.53
Anderson-Darling 5% Critical Value	0.745	95% Hall's Bootstrap UCL	31.31
Kolmogorov-Smirnov Test Statistic	0.148	95% Percentile Bootstrap UCL	19.75
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL	20.93
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	23.87
		97.5% Chebyshev(Mean, Sd) UCL	26.85
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	32.7
95% Approximate Gamma UCL	19.39		
95% Adjusted Gamma UCL	19.56		

Potential UCL to Use		
	Use 95% Approximate Gamma UCL	19.39

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (chrysene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	64

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.783	Maximum of Log Data	-0.245
Mean	0.0244	Mean of log Data	-5.404
Median	0.00187	SD of log Data	1.381
SD	0.0971		
Coefficient of Variation	3.983		
Skewness	6.473		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.407	Lilliefors Test Statistic	0.249
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0402	95% H-UCL	0.0166
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0206
95% Adjusted-CLT UCL (Chen-1995)	0.0465	97.5% Chebyshev (MVUE) UCL	0.0245
95% Modified-t UCL (Johnson-1978)	0.0412	99% Chebyshev (MVUE) UCL	0.0322

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.386	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0632		
MLE of Mean	0.0244		
MLE of Standard Deviation	0.0393		
nu star	80.27		
Approximate Chi Square Value (.05)	60.63	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0477	95% CLT UCL	0.0401
Adjusted Chi Square Value	60.39	95% Jackknife UCL	0.0402
		95% Standard Bootstrap UCL	0.0398
Anderson-Darling Test Statistic	16.25	95% Bootstrap-t UCL	0.0753
Anderson-Darling 5% Critical Value	0.845	95% Hall's Bootstrap UCL	0.0969
Kolmogorov-Smirnov Test Statistic	0.307	95% Percentile Bootstrap UCL	0.0403
Kolmogorov-Smirnov 5% Critical Value	0.0949	95% BCA Bootstrap UCL	0.0481
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0659
		97.5% Chebyshev(Mean, Sd) UCL	0.0839
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.119
95% Approximate Gamma UCL	0.0323		
95% Adjusted Gamma UCL	0.0324		

Potential UCL to Use		
Use 95% Chebyshev (Mean, Sd) UCL	0.0659	

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (cis-1,2-dichloroethylene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	23

Raw Statistics		Log-transformed Statistics	
Minimum	0.00505	Minimum of Log Data	-5.288
Maximum	0.0158	Maximum of Log Data	-4.148
Mean	0.00916	Mean of log Data	-4.762
Median	0.00753	SD of log Data	0.375
SD	0.00356		
Coefficient of Variation	0.389		
Skewness	0.666		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.868	Shapiro Wilk Test Statistic	0.901
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0104	95% H-UCL	0.0105
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0121
95% Adjusted-CLT UCL (Chen-1995)	0.0104	97.5% Chebyshev (MVUE) UCL	0.0134
95% Modified-t UCL (Johnson-1978)	0.0104	99% Chebyshev (MVUE) UCL	0.016

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	6.556	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0014		
MLE of Mean	0.00916		
MLE of Standard Deviation	0.00358		
nu star	340.9		
Approximate Chi Square Value (.05)	299.1	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.0103
Adjusted Chi Square Value	296.5	95% Jackknife UCL	0.0104
		95% Standard Bootstrap UCL	0.0103
Anderson-Darling Test Statistic	1.09	95% Bootstrap-t UCL	0.0104
Anderson-Darling 5% Critical Value	0.745	95% Hall's Bootstrap UCL	0.0104
Kolmogorov-Smirnov Test Statistic	0.175	95% Percentile Bootstrap UCL	0.0103
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL	0.0104
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0122
		97.5% Chebyshev(Mean, Sd) UCL	0.0135
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0161
95% Approximate Gamma UCL	0.0104		
95% Adjusted Gamma UCL	0.0105		

Potential UCL to Use	
Use 95% Student's-t UCL	0.0104
or 95% Modified-t UCL	0.0104

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (copper)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	23

Raw Statistics		Log-transformed Statistics	
Minimum	11.4	Minimum of Log Data	2.434
Maximum	37.2	Maximum of Log Data	3.616
Mean	22.27	Mean of log Data	3.059
Median	19.6	SD of log Data	0.303
SD	6.939		
Coefficient of Variation	0.312		
Skewness	0.759		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.92	Shapiro Wilk Test Statistic	0.961
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data appear Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	24.59	95% H-UCL	24.89
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	28.11
95% Adjusted-CLT UCL (Chen-1995)	24.72	97.5% Chebyshev (MVUE) UCL	30.64
95% Modified-t UCL (Johnson-1978)	24.63	99% Chebyshev (MVUE) UCL	35.61

Gamma Distribution Test		Data Distribution
k star (bias corrected)	10.09	**Data appear Normal at 5% Significance Level**
Theta Star	2.207	
MLE of Mean	22.27	
MLE of Standard Deviation	7.011	
nu star	524.6	
Approximate Chi Square Value (.05)	472.5	**Nonparametric Statistics**
Adjusted Level of Significance	0.0398	95% CLT UCL 24.51
Adjusted Chi Square Value	469.2	95% Jackknife UCL 24.59
		95% Standard Bootstrap UCL 24.49
Anderson-Darling Test Statistic	0.573	95% Bootstrap-t UCL 24.8
Anderson-Darling 5% Critical Value	0.744	95% Hall's Bootstrap UCL 24.69
Kolmogorov-Smirnov Test Statistic	0.165	95% Percentile Bootstrap UCL 24.51
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL 24.64
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 28.2
		97.5% Chebyshev(Mean, Sd) UCL 30.77
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 35.81
95% Approximate Gamma UCL	24.73	
95% Adjusted Gamma UCL	24.9	

Potential UCL to Use	
Use 95% Student's-t UCL	24.59

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (cyanide)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	12

Raw Statistics		Log-transformed Statistics	
Minimum	0.03	Minimum of Log Data	-3.507
Maximum	0.15	Maximum of Log Data	-1.897
Mean	0.0496	Mean of log Data	-3.141
Median	0.03	SD of log Data	0.492
SD	0.0317		
Coefficient of Variation	0.638		
Skewness	2.059		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.683	Shapiro Wilk Test Statistic	0.767
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0602	95% H-UCL	0.0592
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0699
95% Adjusted-CLT UCL (Chen-1995)	0.0625	97.5% Chebyshev (MVUE) UCL	0.0791
95% Modified-t UCL (Johnson-1978)	0.0606	99% Chebyshev (MVUE) UCL	0.0971

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	3.388	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0146		
MLE of Mean	0.0496		
MLE of Standard Deviation	0.027		
nu star	176.2		
Approximate Chi Square Value (.05)	146.5	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.0598
Adjusted Chi Square Value	144.7	95% Jackknife UCL	0.0602
		95% Standard Bootstrap UCL	0.0599
Anderson-Darling Test Statistic	2.598	95% Bootstrap-t UCL	0.0665
Anderson-Darling 5% Critical Value	0.748	95% Hall's Bootstrap UCL	0.0707
Kolmogorov-Smirnov Test Statistic	0.305	95% Percentile Bootstrap UCL	0.0605
Kolmogorov-Smirnov 5% Critical Value	0.172	95% BCA Bootstrap UCL	0.0636
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0767
		97.5% Chebyshev(Mean, Sd) UCL	0.0884
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.111
95% Approximate Gamma UCL	0.0597		
95% Adjusted Gamma UCL	0.0604		

Potential UCL to Use	
Use 95% Student's-t UCL	0.0602
or 95% Modified-t UCL	0.0606

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (cyclohexane)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	23

Raw Statistics		Log-transformed Statistics	
Minimum	0.00505	Minimum of Log Data	-5.288
Maximum	0.1	Maximum of Log Data	-2.303
Mean	0.0139	Mean of log Data	-4.539
Median	0.0102	SD of log Data	0.585
SD	0.018		
Coefficient of Variation	1.294		
Skewness	4.726		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.386	Shapiro Wilk Test Statistic	0.81
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.0199	95% H-UCL	0.0161
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0192
95% Adjusted-CLT UCL (Chen-1995)	0.0232	97.5% Chebyshev (MVUE) UCL	0.0221
95% Modified-t UCL (Johnson-1978)	0.0205	99% Chebyshev (MVUE) UCL	0.0278

Gamma Distribution Test		Data Distribution
k star (bias corrected)	1.843	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.00754	
MLE of Mean	0.0139	
MLE of Standard Deviation	0.0102	
nu star	95.86	
Approximate Chi Square Value (.05)	74.28	**Nonparametric Statistics**
Adjusted Level of Significance	0.0398	95% CLT UCL 0.0197
Adjusted Chi Square Value	73.02	95% Jackknife UCL 0.0199
		95% Standard Bootstrap UCL 0.0194
Anderson-Darling Test Statistic	2.445	95% Bootstrap-t UCL 0.037
Anderson-Darling 5% Critical Value	0.757	95% Hall's Bootstrap UCL 0.0434
Kolmogorov-Smirnov Test Statistic	0.26	95% Percentile Bootstrap UCL 0.0209
Kolmogorov-Smirnov 5% Critical Value	0.173	95% BCA Bootstrap UCL 0.0244
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0293
		97.5% Chebyshev(Mean, Sd) UCL 0.0359
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.049
95% Approximate Gamma UCL	0.0179	
95% Adjusted Gamma UCL	0.0182	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0293

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (dibenzo(a,h)anthracene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	54

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.097	Maximum of Log Data	-2.333
Mean	0.0072	Mean of log Data	-5.613
Median	0.00182	SD of log Data	1.03
SD	0.013		
Coefficient of Variation	1.812		
Skewness	4.61		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.337	Lilliefors Test Statistic	0.287
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.00932	95% H-UCL	0.00778
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00943
95% Adjusted-CLT UCL (Chen-1995)	0.00992	97.5% Chebyshev (MVUE) UCL	0.0108
95% Modified-t UCL (Johnson-1978)	0.00942	99% Chebyshev (MVUE) UCL	0.0136

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.846	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.00851	
MLE of Mean	0.0072	
MLE of Standard Deviation	0.00783	
nu star	176	
Approximate Chi Square Value (.05)	146.3	**Nonparametric Statistics**
Adjusted Level of Significance	0.0477	95% CLT UCL 0.0093
Adjusted Chi Square Value	146	95% Jackknife UCL 0.00932
		95% Standard Bootstrap UCL 0.00927
Anderson-Darling Test Statistic	10.43	95% Bootstrap-t UCL 0.0105
Anderson-Darling 5% Critical Value	0.79	95% Hall's Bootstrap UCL 0.0108
Kolmogorov-Smirnov Test Statistic	0.287	95% Percentile Bootstrap UCL 0.00948
Kolmogorov-Smirnov 5% Critical Value	0.0915	95% BCA Bootstrap UCL 0.0101
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0128
		97.5% Chebyshev(Mean, Sd) UCL 0.0152
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0199
95% Approximate Gamma UCL	0.00866	
95% Adjusted Gamma UCL	0.00868	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0128

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (dibenzofuran)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.415
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.52
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.519
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.593
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use			
		Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (dro)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	24

Raw Statistics		Log-transformed Statistics	
Minimum	6.35	Minimum of Log Data	1.848
Maximum	869	Maximum of Log Data	6.767
Mean	63.25	Mean of log Data	2.899
Median	8.61	SD of log Data	1.317
SD	170.6		
Coefficient of Variation	2.697		
Skewness	4.568		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.364	Shapiro Wilk Test Statistic	0.791
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	120.4	95% H-UCL	93.82
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	96.19
95% Adjusted-CLT UCL (Chen-1995)	150.3	97.5% Chebyshev (MVUE) UCL	120.2
95% Modified-t UCL (Johnson-1978)	125.4	99% Chebyshev (MVUE) UCL	167.2

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.475	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	133.3		
MLE of Mean	63.25		
MLE of Standard Deviation	91.81		
nu star	24.68		
Approximate Chi Square Value (.05)	14.37	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	118.3
Adjusted Chi Square Value	13.85	95% Jackknife UCL	120.4
		95% Standard Bootstrap UCL	116.7
Anderson-Darling Test Statistic	3.342	95% Bootstrap-t UCL	327.5
Anderson-Darling 5% Critical Value	0.808	95% Hall's Bootstrap UCL	309.2
Kolmogorov-Smirnov Test Statistic	0.276	95% Percentile Bootstrap UCL	125.2
Kolmogorov-Smirnov 5% Critical Value	0.181	95% BCA Bootstrap UCL	164.3
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	209.1
		97.5% Chebyshev(Mean, Sd) UCL	272.2
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	396.1
95% Approximate Gamma UCL	108.7		
95% Adjusted Gamma UCL	112.7		

Potential UCL to Use		
	Use 95% Chebyshev (Mean, Sd) UCL	209.1

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (ethylbenzene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	78

Raw Statistics		Log-transformed Statistics	
Minimum	0.0047	Minimum of Log Data	-5.36
Maximum	2.36	Maximum of Log Data	0.859
Mean	0.0788	Mean of log Data	-4.442
Median	0.00808	SD of log Data	1.221
SD	0.326		
Coefficient of Variation	4.136		
Skewness	5.496		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.48	Lilliefors Test Statistic	0.309
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.132	95% H-UCL	0.0332
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0409
95% Adjusted-CLT UCL (Chen-1995)	0.15	97.5% Chebyshev (MVUE) UCL	0.0479
95% Modified-t UCL (Johnson-1978)	0.135	99% Chebyshev (MVUE) UCL	0.0619

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.349	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.226	
MLE of Mean	0.0788	
MLE of Standard Deviation	0.133	
nu star	72.65	
Approximate Chi Square Value (.05)	54.02	**Nonparametric Statistics**
Adjusted Level of Significance	0.0477	95% CLT UCL 0.131
Adjusted Chi Square Value	53.8	95% Jackknife UCL 0.132
		95% Standard Bootstrap UCL 0.131
Anderson-Darling Test Statistic	27.44	95% Bootstrap-t UCL 0.192
Anderson-Darling 5% Critical Value	0.855	95% Hall's Bootstrap UCL 0.141
Kolmogorov-Smirnov Test Statistic	0.471	95% Percentile Bootstrap UCL 0.137
Kolmogorov-Smirnov 5% Critical Value	0.0953	95% BCA Bootstrap UCL 0.148
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.218
		97.5% Chebyshev(Mean, Sd) UCL 0.279
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.397
95% Approximate Gamma UCL	0.106	
95% Adjusted Gamma UCL	0.106	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.218

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (fluoranthene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	59

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.119	Maximum of Log Data	-2.129
Mean	0.00872	Mean of log Data	-5.518
Median	0.00186	SD of log Data	1.098
SD	0.0171		
Coefficient of Variation	1.963		
Skewness	4.557		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.337	Lilliefors Test Statistic	0.273
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0115	95% H-UCL	0.00941
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0115
95% Adjusted-CLT UCL (Chen-1995)	0.0123	97.5% Chebyshev (MVUE) UCL	0.0133
95% Modified-t UCL (Johnson-1978)	0.0116	99% Chebyshev (MVUE) UCL	0.0169

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.754	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0116		
MLE of Mean	0.00872		
MLE of Standard Deviation	0.01		
nu star	156.8		
Approximate Chi Square Value (.05)	128.8	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0477	95% CLT UCL	0.0115
Adjusted Chi Square Value	128.5	95% Jackknife UCL	0.0115
		95% Standard Bootstrap UCL	0.0115
Anderson-Darling Test Statistic	9.771	95% Bootstrap-t UCL	0.0133
Anderson-Darling 5% Critical Value	0.794	95% Hall's Bootstrap UCL	0.0138
Kolmogorov-Smirnov Test Statistic	0.268	95% Percentile Bootstrap UCL	0.0116
Kolmogorov-Smirnov 5% Critical Value	0.0918	95% BCA Bootstrap UCL	0.0123
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.016
		97.5% Chebyshev(Mean, Sd) UCL	0.0192
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0254
95% Approximate Gamma UCL	0.0106		
95% Adjusted Gamma UCL	0.0106		

Potential UCL to Use		
	Use 95% Chebyshev (Mean, Sd) UCL	0.016

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (fluorene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	58

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.207	Maximum of Log Data	-1.575
Mean	0.0112	Mean of log Data	-5.478
Median	0.00188	SD of log Data	1.164
SD	0.0297		
Coefficient of Variation	2.658		
Skewness	5.634		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.373	Lilliefors Test Statistic	0.262
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.016	95% H-UCL	0.0108
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0132
95% Adjusted-CLT UCL (Chen-1995)	0.0177	97.5% Chebyshev (MVUE) UCL	0.0155
95% Modified-t UCL (Johnson-1978)	0.0163	99% Chebyshev (MVUE) UCL	0.0198

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.613	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0182		
MLE of Mean	0.0112		
MLE of Standard Deviation	0.0143		
nu star	127.4		
Approximate Chi Square Value (.05)	102.4	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0477	95% CLT UCL	0.016
Adjusted Chi Square Value	102	95% Jackknife UCL	0.016
		95% Standard Bootstrap UCL	0.0159
Anderson-Darling Test Statistic	11.05	95% Bootstrap-t UCL	0.024
Anderson-Darling 5% Critical Value	0.807	95% Hall's Bootstrap UCL	0.0336
Kolmogorov-Smirnov Test Statistic	0.25	95% Percentile Bootstrap UCL	0.0165
Kolmogorov-Smirnov 5% Critical Value	0.0927	95% BCA Bootstrap UCL	0.0178
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0239
		97.5% Chebyshev(Mean, Sd) UCL	0.0294
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0402
95% Approximate Gamma UCL	0.0139		
95% Adjusted Gamma UCL	0.014		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0239

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (gro)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	24

Raw Statistics		Log-transformed Statistics	
Minimum	0.488	Minimum of Log Data	-0.717
Maximum	5.35	Maximum of Log Data	1.677
Mean	1.162	Mean of log Data	-0.0369
Median	0.771	SD of log Data	0.563
SD	0.968		
Coefficient of Variation	0.833		
Skewness	3.468		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.609	Shapiro Wilk Test Statistic	0.889
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	1.486	95% H-UCL	1.418
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.69
95% Adjusted-CLT UCL (Chen-1995)	1.612	97.5% Chebyshev (MVUE) UCL	1.936
95% Modified-t UCL (Johnson-1978)	1.507	99% Chebyshev (MVUE) UCL	2.419

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	2.532	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.459		
MLE of Mean	1.162		
MLE of Standard Deviation	0.73		
nu star	131.6		
Approximate Chi Square Value (.05)	106.1	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	1.474
Adjusted Chi Square Value	104.6	95% Jackknife UCL	1.486
		95% Standard Bootstrap UCL	1.466
Anderson-Darling Test Statistic	1.258	95% Bootstrap-t UCL	1.779
Anderson-Darling 5% Critical Value	0.752	95% Hall's Bootstrap UCL	2.777
Kolmogorov-Smirnov Test Statistic	0.196	95% Percentile Bootstrap UCL	1.508
Kolmogorov-Smirnov 5% Critical Value	0.173	95% BCA Bootstrap UCL	1.656
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1.989
		97.5% Chebyshev(Mean, Sd) UCL	2.347
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	3.05
95% Approximate Gamma UCL	1.441		
95% Adjusted Gamma UCL	1.462		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	1.989

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (hexachloro-1,3-butadiene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.413
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.37
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.589
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.592
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (hexachlorobenzene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.417
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.64
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.877
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.592
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (hexachlorocyclopentadiene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	19

Raw Statistics		Log-transformed Statistics	
Minimum	0.201	Minimum of Log Data	-1.604
Maximum	8.65	Maximum of Log Data	2.158
Mean	0.542	Mean of log Data	-1.385
Median	0.211	SD of log Data	0.726
SD	1.654		
Coefficient of Variation	3.05		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.278
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	1.096	95% H-UCL	0.447
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.538
95% Adjusted-CLT UCL (Chen-1995)	1.422	97.5% Chebyshev (MVUE) UCL	0.632
95% Modified-t UCL (Johnson-1978)	1.15	99% Chebyshev (MVUE) UCL	0.816

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.765		
MLE of Mean	0.542		
MLE of Standard Deviation	0.644		
nu star	36.84		
Approximate Chi Square Value (.05)	23.94	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	1.076
Adjusted Chi Square Value	23.26	95% Jackknife UCL	1.096
		95% Standard Bootstrap UCL	1.066
Anderson-Darling Test Statistic	9.154	95% Bootstrap-t UCL	40.28
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	19.92
Kolmogorov-Smirnov Test Statistic	0.528	95% Percentile Bootstrap UCL	1.19
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	1.517
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1.956
		97.5% Chebyshev(Mean, Sd) UCL	2.568
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	3.769
95% Approximate Gamma UCL	0.834		
95% Adjusted Gamma UCL	0.859		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	1.956

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (hexachloroethane)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.416
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.37
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.679
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.593
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (indeno(1,2,3-c,d)pyrene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	55

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.097	Maximum of Log Data	-2.333
Mean	0.00778	Mean of log Data	-5.593
Median	0.00182	SD of log Data	1.066
SD	0.0144		
Coefficient of Variation	1.848		
Skewness	4.104		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.347	Lilliefors Test Statistic	0.286
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.0101	95% H-UCL	0.00834
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0101
95% Adjusted-CLT UCL (Chen-1995)	0.0107	97.5% Chebyshev (MVUE) UCL	0.0117
95% Modified-t UCL (Johnson-1978)	0.0102	99% Chebyshev (MVUE) UCL	0.0148

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.789	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.00986	
MLE of Mean	0.00778	
MLE of Standard Deviation	0.00876	
nu star	164	
Approximate Chi Square Value (.05)	135.4	**Nonparametric Statistics**
Adjusted Level of Significance	0.0477	95% CLT UCL 0.0101
Adjusted Chi Square Value	135.1	95% Jackknife UCL 0.0101
		95% Standard Bootstrap UCL 0.0101
Anderson-Darling Test Statistic	10.8	95% Bootstrap-t UCL 0.0115
Anderson-Darling 5% Critical Value	0.792	95% Hall's Bootstrap UCL 0.011
Kolmogorov-Smirnov Test Statistic	0.286	95% Percentile Bootstrap UCL 0.0102
Kolmogorov-Smirnov 5% Critical Value	0.0917	95% BCA Bootstrap UCL 0.0108
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0139
		97.5% Chebyshev(Mean, Sd) UCL 0.0166
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0218
95% Approximate Gamma UCL	0.00942	
95% Adjusted Gamma UCL	0.00945	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0139

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (iron)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	24

Raw Statistics		Log-transformed Statistics	
Minimum	7790	Minimum of Log Data	8.961
Maximum	29000	Maximum of Log Data	10.28
Mean	15081	Mean of log Data	9.565
Median	12900	SD of log Data	0.333
SD	5471		
Coefficient of Variation	0.363		
Skewness	1.149		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.879	Shapiro Wilk Test Statistic	0.951
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	16914	95% H-UCL	17033
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	19398
95% Adjusted-CLT UCL (Chen-1995)	17104	97.5% Chebyshev (MVUE) UCL	21284
95% Modified-t UCL (Johnson-1978)	16954	99% Chebyshev (MVUE) UCL	24990

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	8.069	**Data Follow Appr. Gamma Distribution at 5% Significance Level**	
Theta Star	1869		
MLE of Mean	15081		
MLE of Standard Deviation	5309		
nu star	419.6		
Approximate Chi Square Value (.05)	373.1	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	16846
Adjusted Chi Square Value	370.2	95% Jackknife UCL	16914
		95% Standard Bootstrap UCL	16816
Anderson-Darling Test Statistic	0.749	95% Bootstrap-t UCL	17329
Anderson-Darling 5% Critical Value	0.745	95% Hall's Bootstrap UCL	17053
Kolmogorov-Smirnov Test Statistic	0.166	95% Percentile Bootstrap UCL	16900
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL	17282
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	19758
		97.5% Chebyshev(Mean, Sd) UCL	21781
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	25756
95% Approximate Gamma UCL	16960		
95% Adjusted Gamma UCL	17093		

Potential UCL to Use	
Use 95% Approximate Gamma UCL	16960

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (isophorone)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.416
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.73
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	8.01
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.593
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (isopropylbenzene (cumene))

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	23

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0051	Minimum of Log Data	-5.279
Maximum	0.0158	Maximum of Log Data	-4.148
Mean	0.00928	Mean of log Data	-4.744
Median	0.0079	SD of log Data	0.36
SD	0.00347		
Coefficient of Variation	0.374		
Skewness	0.68		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.871	Shapiro Wilk Test Statistic	0.905
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0104	95% H-UCL	0.0106
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0122
95% Adjusted-CLT UCL (Chen-1995)	0.0105	97.5% Chebyshev (MVUE) UCL	0.0134
95% Modified-t UCL (Johnson-1978)	0.0105	99% Chebyshev (MVUE) UCL	0.0159

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	7.105	**Data Follow Appr. Gamma Distribution at 5% Significance Level**
Theta Star	0.00131	
MLE of Mean	0.00928	
MLE of Standard Deviation	0.00348	
nu star	369.4	
Approximate Chi Square Value (.05)	325.9	**Nonparametric Statistics**
Adjusted Level of Significance	0.0398	95% CLT UCL 0.0104
Adjusted Chi Square Value	323.2	95% Jackknife UCL 0.0104
		95% Standard Bootstrap UCL 0.0104
Anderson-Darling Test Statistic	1.044	95% Bootstrap-t UCL 0.0106
Anderson-Darling 5% Critical Value	0.745	95% Hall's Bootstrap UCL 0.0104
Kolmogorov-Smirnov Test Statistic	0.159	95% Percentile Bootstrap UCL 0.0104
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL 0.0106
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0122
		97.5% Chebyshev(Mean, Sd) UCL 0.0135
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.016
95% Approximate Gamma UCL	0.0105	
95% Adjusted Gamma UCL	0.0106	

Potential UCL to Use Use 95% Approximate Gamma UCL 0.0105

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (m,p-xylene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	85

Raw Statistics		Log-transformed Statistics	
Minimum	0.00905	Minimum of Log Data	-4.705
Maximum	8.39	Maximum of Log Data	2.127
Mean	0.172	Mean of log Data	-3.756
Median	0.0159	SD of log Data	1.249
SD	0.876		
Coefficient of Variation	5.084		
Skewness	8.403		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.463	Lilliefors Test Statistic	0.291
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.315	95% H-UCL	0.069
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0851
95% Adjusted-CLT UCL (Chen-1995)	0.389	97.5% Chebyshev (MVUE) UCL	0.1
95% Modified-t UCL (Johnson-1978)	0.327	99% Chebyshev (MVUE) UCL	0.13

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.335	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.514		
MLE of Mean	0.172		
MLE of Standard Deviation	0.298		
nu star	69.7		
Approximate Chi Square Value (.05)	51.48	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0477	95% CLT UCL	0.314
Adjusted Chi Square Value	51.26	95% Jackknife UCL	0.315
		95% Standard Bootstrap UCL	0.312
Anderson-Darling Test Statistic	26.84	95% Bootstrap-t UCL	0.681
Anderson-Darling 5% Critical Value	0.858	95% Hall's Bootstrap UCL	0.758
Kolmogorov-Smirnov Test Statistic	0.449	95% Percentile Bootstrap UCL	0.334
Kolmogorov-Smirnov 5% Critical Value	0.0955	95% BCA Bootstrap UCL	0.441
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.547
		97.5% Chebyshev(Mean, Sd) UCL	0.709
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.027
95% Approximate Gamma UCL	0.233		
95% Adjusted Gamma UCL	0.234		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.547

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (methyl tert-butyl ether (mtbe))

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	24

Raw Statistics		Log-transformed Statistics	
Minimum	0.0202	Minimum of Log Data	-3.902
Maximum	0.063	Maximum of Log Data	-2.765
Mean	0.0364	Mean of log Data	-3.382
Median	0.0299	SD of log Data	0.374
SD	0.0141		
Coefficient of Variation	0.388		
Skewness	0.669		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.868	Shapiro Wilk Test Statistic	0.901
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0411	95% H-UCL	0.0419
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0482
95% Adjusted-CLT UCL (Chen-1995)	0.0413	97.5% Chebyshev (MVUE) UCL	0.0534
95% Modified-t UCL (Johnson-1978)	0.0412	99% Chebyshev (MVUE) UCL	0.0635

Gamma Distribution Test		Data Distribution
k star (bias corrected)	6.585	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.00553	
MLE of Mean	0.0364	
MLE of Standard Deviation	0.0142	
nu star	342.4	
Approximate Chi Square Value (.05)	300.5	**Nonparametric Statistics**
Adjusted Level of Significance	0.0398	95% CLT UCL 0.041
Adjusted Chi Square Value	298	95% Jackknife UCL 0.0411
		95% Standard Bootstrap UCL 0.0409
Anderson-Darling Test Statistic	1.089	95% Bootstrap-t UCL 0.0416
Anderson-Darling 5% Critical Value	0.745	95% Hall's Bootstrap UCL 0.0412
Kolmogorov-Smirnov Test Statistic	0.176	95% Percentile Bootstrap UCL 0.0411
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL 0.0414
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0485
		97.5% Chebyshev(Mean, Sd) UCL 0.0537
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.064
95% Approximate Gamma UCL	0.0415	
95% Adjusted Gamma UCL	0.0418	

Potential UCL to Use	
Use 95% Student's-t UCL	0.0411
or 95% Modified-t UCL	0.0412

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (methylene chloride)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	24

Raw Statistics		Log-transformed Statistics	
Minimum	0.0202	Minimum of Log Data	-3.902
Maximum	0.063	Maximum of Log Data	-2.765
Mean	0.0381	Mean of log Data	-3.344
Median	0.0299	SD of log Data	0.398
SD	0.0152		
Coefficient of Variation	0.398		
Skewness	0.418		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.856	Shapiro Wilk Test Statistic	0.875
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0432	95% H-UCL	0.0444
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0514
95% Adjusted-CLT UCL (Chen-1995)	0.0433	97.5% Chebyshev (MVUE) UCL	0.0572
95% Modified-t UCL (Johnson-1978)	0.0432	99% Chebyshev (MVUE) UCL	0.0685

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	5.957	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0064		
MLE of Mean	0.0381		
MLE of Standard Deviation	0.0156		
nu star	309.7		
Approximate Chi Square Value (.05)	270	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.043
Adjusted Chi Square Value	267.5	95% Jackknife UCL	0.0432
		95% Standard Bootstrap UCL	0.0429
Anderson-Darling Test Statistic	1.38	95% Bootstrap-t UCL	0.0434
Anderson-Darling 5% Critical Value	0.746	95% Hall's Bootstrap UCL	0.0432
Kolmogorov-Smirnov Test Statistic	0.206	95% Percentile Bootstrap UCL	0.0432
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL	0.0431
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0511
		97.5% Chebyshev(Mean, Sd) UCL	0.0567
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0677
95% Approximate Gamma UCL	0.0437		
95% Adjusted Gamma UCL	0.0441		

Potential UCL to Use	
Use 95% Student's-t UCL	0.0432
or 95% Modified-t UCL	0.0432

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (naphthalene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	65

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.631	Maximum of Log Data	-0.46
Mean	0.0236	Mean of log Data	-5.314
Median	0.00308	SD of log Data	1.356
SD	0.0834		
Coefficient of Variation	3.538		
Skewness	5.564		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.417	Lilliefors Test Statistic	0.2
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.0371	95% H-UCL	0.0174
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0215
95% Adjusted-CLT UCL (Chen-1995)	0.0418	97.5% Chebyshev (MVUE) UCL	0.0256
95% Modified-t UCL (Johnson-1978)	0.0379	99% Chebyshev (MVUE) UCL	0.0335

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.412	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0573	
MLE of Mean	0.0236	
MLE of Standard Deviation	0.0367	
nu star	85.61	
Approximate Chi Square Value (.05)	65.28	**Nonparametric Statistics**
Adjusted Level of Significance	0.0477	95% CLT UCL 0.037
Adjusted Chi Square Value	65.04	95% Jackknife UCL 0.0371
		95% Standard Bootstrap UCL 0.0372
Anderson-Darling Test Statistic	15.07	95% Bootstrap-t UCL 0.0502
Anderson-Darling 5% Critical Value	0.839	95% Hall's Bootstrap UCL 0.0408
Kolmogorov-Smirnov Test Statistic	0.304	95% Percentile Bootstrap UCL 0.0376
Kolmogorov-Smirnov 5% Critical Value	0.0945	95% BCA Bootstrap UCL 0.0427
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0592
		97.5% Chebyshev(Mean, Sd) UCL 0.0746
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.105
95% Approximate Gamma UCL	0.0309	
95% Adjusted Gamma UCL	0.031	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0592

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (n-butylbenzene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	23

Raw Statistics		Log-transformed Statistics	
Minimum	0.00505	Minimum of Log Data	-5.288
Maximum	0.0158	Maximum of Log Data	-4.148
Mean	0.0093	Mean of log Data	-4.744
Median	0.00795	SD of log Data	0.369
SD	0.0035		
Coefficient of Variation	0.377		
Skewness	0.599		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.889	Shapiro Wilk Test Statistic	0.919
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0105	95% H-UCL	0.0107
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0123
95% Adjusted-CLT UCL (Chen-1995)	0.0105	97.5% Chebyshev (MVUE) UCL	0.0136
95% Modified-t UCL (Johnson-1978)	0.0105	99% Chebyshev (MVUE) UCL	0.0161

Gamma Distribution Test		Data Distribution
k star (bias corrected)	6.84	**Data Follow Appr. Gamma Distribution at 5% Significance Level**
Theta Star	0.00136	
MLE of Mean	0.0093	
MLE of Standard Deviation	0.00356	
nu star	355.7	
Approximate Chi Square Value (.05)	313	**Nonparametric Statistics**
Adjusted Level of Significance	0.0398	95% CLT UCL 0.0104
Adjusted Chi Square Value	310.3	95% Jackknife UCL 0.0105
		95% Standard Bootstrap UCL 0.0104
Anderson-Darling Test Statistic	0.83	95% Bootstrap-t UCL 0.0106
Anderson-Darling 5% Critical Value	0.745	95% Hall's Bootstrap UCL 0.0105
Kolmogorov-Smirnov Test Statistic	0.156	95% Percentile Bootstrap UCL 0.0104
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL 0.0105
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0123
		97.5% Chebyshev(Mean, Sd) UCL 0.0136
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0161
95% Approximate Gamma UCL	0.0106	
95% Adjusted Gamma UCL	0.0107	

Potential UCL to Use Use 95% Approximate Gamma UCL 0.0106

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (n-hexane)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	24

Raw Statistics		Log-transformed Statistics	
Minimum	0.00505	Minimum of Log Data	-5.288
Maximum	0.116	Maximum of Log Data	-2.154
Mean	0.0157	Mean of log Data	-4.569
Median	0.00795	SD of log Data	0.742
SD	0.0237		
Coefficient of Variation	1.507		
Skewness	3.703		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.441	Shapiro Wilk Test Statistic	0.774
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0236	95% H-UCL	0.0189
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0227
95% Adjusted-CLT UCL (Chen-1995)	0.0269	97.5% Chebyshev (MVUE) UCL	0.0268
95% Modified-t UCL (Johnson-1978)	0.0242	99% Chebyshev (MVUE) UCL	0.0346

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	1.218	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0129		
MLE of Mean	0.0157		
MLE of Standard Deviation	0.0142		
nu star	63.32		
Approximate Chi Square Value (.05)	46.02	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.0233
Adjusted Chi Square Value	45.04	95% Jackknife UCL	0.0236
		95% Standard Bootstrap UCL	0.0233
Anderson-Darling Test Statistic	3.218	95% Bootstrap-t UCL	0.0565
Anderson-Darling 5% Critical Value	0.765	95% Hall's Bootstrap UCL	0.0635
Kolmogorov-Smirnov Test Statistic	0.282	95% Percentile Bootstrap UCL	0.024
Kolmogorov-Smirnov 5% Critical Value	0.175	95% BCA Bootstrap UCL	0.0282
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0359
		97.5% Chebyshev(Mean, Sd) UCL	0.0447
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0619
95% Approximate Gamma UCL	0.0216		
95% Adjusted Gamma UCL	0.0221		

Potential UCL to Use		
	Use 95% Chebyshev (Mean, Sd) UCL	0.0359

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (nickel)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	23

Raw Statistics		Log-transformed Statistics	
Minimum	11.2	Minimum of Log Data	2.416
Maximum	28.5	Maximum of Log Data	3.35
Mean	18.63	Mean of log Data	2.893
Median	18.05	SD of log Data	0.257
SD	4.884		
Coefficient of Variation	0.262		
Skewness	0.618		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.938	Shapiro Wilk Test Statistic	0.968
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data appear Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	20.27	95% H-UCL	20.45
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	22.77
95% Adjusted-CLT UCL (Chen-1995)	20.33	97.5% Chebyshev (MVUE) UCL	24.57
95% Modified-t UCL (Johnson-1978)	20.29	99% Chebyshev (MVUE) UCL	28.09
Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	13.96	**Data appear Normal at 5% Significance Level**	
Theta Star	1.335		
MLE of Mean	18.63		
MLE of Standard Deviation	4.987		
nu star	725.7		
Approximate Chi Square Value (.05)	664.2	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	20.21
Adjusted Chi Square Value	660.3	95% Jackknife UCL	20.27
		95% Standard Bootstrap UCL	20.17
Anderson-Darling Test Statistic	0.32	95% Bootstrap-t UCL	20.42
Anderson-Darling 5% Critical Value	0.744	95% Hall's Bootstrap UCL	20.33
Kolmogorov-Smirnov Test Statistic	0.0993	95% Percentile Bootstrap UCL	20.22
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL	20.37
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	22.81
		97.5% Chebyshev(Mean, Sd) UCL	24.61
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	28.16
95% Approximate Gamma UCL	20.36		
95% Adjusted Gamma UCL	20.48		
Potential UCL to Use		Use 95% Student's-t UCL	20.27

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (nitrobenzene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.421
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.25
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.587
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.594
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (n-nitrosodimethylamine)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.42
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.5
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.525
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.592
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (n-nitroso-di-n-propylamine)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.418
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.69
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.668
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.594
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (n-nitrosodiphenylamine)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	21

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	3.38	Maximum of Log Data	1.218
Mean	0.212	Mean of log Data	-2.325
Median	0.0823	SD of log Data	0.727
SD	0.646		
Coefficient of Variation	3.051		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.279
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.428	95% H-UCL	0.175
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.21
95% Adjusted-CLT UCL (Chen-1995)	0.556	97.5% Chebyshev (MVUE) UCL	0.247
95% Modified-t UCL (Johnson-1978)	0.449	99% Chebyshev (MVUE) UCL	0.319

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.708	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.299		
MLE of Mean	0.212		
MLE of Standard Deviation	0.252		
nu star	36.81		
Approximate Chi Square Value (.05)	23.92	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.42
Adjusted Chi Square Value	23.24	95% Jackknife UCL	0.428
		95% Standard Bootstrap UCL	0.414
Anderson-Darling Test Statistic	9.138	95% Bootstrap-t UCL	15.23
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	7.658
Kolmogorov-Smirnov Test Statistic	0.527	95% Percentile Bootstrap UCL	0.465
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	0.592
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.764
		97.5% Chebyshev(Mean, Sd) UCL	1.003
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.473
95% Approximate Gamma UCL	0.326		
95% Adjusted Gamma UCL	0.336		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.764

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (n-propylbenzene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	23

Raw Statistics		Log-transformed Statistics	
Minimum	0.0051	Minimum of Log Data	-5.279
Maximum	0.0158	Maximum of Log Data	-4.148
Mean	0.00942	Mean of log Data	-4.726
Median	0.0082	SD of log Data	0.352
SD	0.00341		
Coefficient of Variation	0.362		
Skewness	0.621		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.892	Shapiro Wilk Test Statistic	0.924
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.0106	95% H-UCL	0.0107
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0123
95% Adjusted-CLT UCL (Chen-1995)	0.0106	97.5% Chebyshev (MVUE) UCL	0.0136
95% Modified-t UCL (Johnson-1978)	0.0106	99% Chebyshev (MVUE) UCL	0.016

Gamma Distribution Test		Data Distribution
k star (bias corrected)	7.464	**Data Follow Appr. Gamma Distribution at 5% Significance Level**
Theta Star	0.00126	
MLE of Mean	0.00942	
MLE of Standard Deviation	0.00345	
nu star	388.1	
Approximate Chi Square Value (.05)	343.5	**Nonparametric Statistics**
Adjusted Level of Significance	0.0398	95% CLT UCL 0.0105
Adjusted Chi Square Value	340.7	95% Jackknife UCL 0.0106
		95% Standard Bootstrap UCL 0.0105
Anderson-Darling Test Statistic	0.794	95% Bootstrap-t UCL 0.0107
Anderson-Darling 5% Critical Value	0.745	95% Hall's Bootstrap UCL 0.0106
Kolmogorov-Smirnov Test Statistic	0.141	95% Percentile Bootstrap UCL 0.0105
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL 0.0106
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0123
		97.5% Chebyshev(Mean, Sd) UCL 0.0136
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0161
95% Approximate Gamma UCL	0.0106	
95% Adjusted Gamma UCL	0.0107	

Potential UCL to Use Use 95% Approximate Gamma UCL 0.0106

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (o-xylene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	82

Raw Statistics		Log-transformed Statistics	
Minimum	0.00446	Minimum of Log Data	-5.413
Maximum	2.98	Maximum of Log Data	1.092
Mean	0.0713	Mean of log Data	-4.428
Median	0.00823	SD of log Data	1.168
SD	0.349		
Coefficient of Variation	4.894		
Skewness	7.211		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.447	Lilliefors Test Statistic	0.271
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.128	95% H-UCL	0.031
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.038
95% Adjusted-CLT UCL (Chen-1995)	0.153	97.5% Chebyshev (MVUE) UCL	0.0444
95% Modified-t UCL (Johnson-1978)	0.132	99% Chebyshev (MVUE) UCL	0.0569

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.368	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.194	
MLE of Mean	0.0713	
MLE of Standard Deviation	0.118	
nu star	76.57	
Approximate Chi Square Value (.05)	57.41	**Nonparametric Statistics**
Adjusted Level of Significance	0.0477	95% CLT UCL 0.128
Adjusted Chi Square Value	57.18	95% Jackknife UCL 0.128
		95% Standard Bootstrap UCL 0.127
Anderson-Darling Test Statistic	25.23	95% Bootstrap-t UCL 0.348
Anderson-Darling 5% Critical Value	0.85	95% Hall's Bootstrap UCL 0.371
Kolmogorov-Smirnov Test Statistic	0.431	95% Percentile Bootstrap UCL 0.137
Kolmogorov-Smirnov 5% Critical Value	0.0951	95% BCA Bootstrap UCL 0.173
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.22
		97.5% Chebyshev(Mean, Sd) UCL 0.285
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.412
95% Approximate Gamma UCL	0.0951	
95% Adjusted Gamma UCL	0.0955	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.22

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (pentachlorophenol)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	19

Raw Statistics		Log-transformed Statistics	
Minimum	0.625	Minimum of Log Data	-0.47
Maximum	26.9	Maximum of Log Data	3.292
Mean	1.685	Mean of log Data	-0.253
Median	0.655	SD of log Data	0.727
SD	5.143		
Coefficient of Variation	3.053		
Skewness	5.098		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.209	Shapiro Wilk Test Statistic	0.277
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	3.408	95% H-UCL	1.389
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.671
95% Adjusted-CLT UCL (Chen-1995)	4.421	97.5% Chebyshev (MVUE) UCL	1.961
95% Modified-t UCL (Johnson-1978)	3.576	99% Chebyshev (MVUE) UCL	2.532

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.707	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	2.382		
MLE of Mean	1.685		
MLE of Standard Deviation	2.003		
nu star	36.78		
Approximate Chi Square Value (.05)	23.9	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	3.344
Adjusted Chi Square Value	23.21	95% Jackknife UCL	3.408
		95% Standard Bootstrap UCL	3.304
Anderson-Darling Test Statistic	9.164	95% Bootstrap-t UCL	125.8
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL	60.46
Kolmogorov-Smirnov Test Statistic	0.529	95% Percentile Bootstrap UCL	3.702
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	4.72
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	6.081
		97.5% Chebyshev(Mean, Sd) UCL	7.984
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	11.72
95% Approximate Gamma UCL	2.593		
95% Adjusted Gamma UCL	2.669		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	6.081

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (phenanthrene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	65

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.675	Maximum of Log Data	-0.393
Mean	0.0233	Mean of log Data	-5.304
Median	0.00246	SD of log Data	1.411
SD	0.0806		
Coefficient of Variation	3.457		
Skewness	6.332		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.393	Lilliefors Test Statistic	0.245
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0365	95% H-UCL	0.0194
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.024
95% Adjusted-CLT UCL (Chen-1995)	0.0416	97.5% Chebyshev (MVUE) UCL	0.0287
95% Modified-t UCL (Johnson-1978)	0.0373	99% Chebyshev (MVUE) UCL	0.0378

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.416	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.056		
MLE of Mean	0.0233		
MLE of Standard Deviation	0.0362		
nu star	86.58		
Approximate Chi Square Value (.05)	66.13	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0477	95% CLT UCL	0.0363
Adjusted Chi Square Value	65.88	95% Jackknife UCL	0.0365
		95% Standard Bootstrap UCL	0.0362
Anderson-Darling Test Statistic	13.61	95% Bootstrap-t UCL	0.0534
Anderson-Darling 5% Critical Value	0.838	95% Hall's Bootstrap UCL	0.0829
Kolmogorov-Smirnov Test Statistic	0.285	95% Percentile Bootstrap UCL	0.0371
Kolmogorov-Smirnov 5% Critical Value	0.0945	95% BCA Bootstrap UCL	0.044
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0578
		97.5% Chebyshev(Mean, Sd) UCL	0.0727
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.102
95% Approximate Gamma UCL	0.0305		
95% Adjusted Gamma UCL	0.0307		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0578

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (pyrene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	60

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	0.106	Maximum of Log Data	-2.244
Mean	0.00865	Mean of log Data	-5.527
Median	0.00186	SD of log Data	1.103
SD	0.0164		
Coefficient of Variation	1.897		
Skewness	4.236		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.351	Lilliefors Test Statistic	0.269
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.0113	95% H-UCL	0.00938
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0115
95% Adjusted-CLT UCL (Chen-1995)	0.012	97.5% Chebyshev (MVUE) UCL	0.0133
95% Modified-t UCL (Johnson-1978)	0.0114	99% Chebyshev (MVUE) UCL	0.0169

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.752	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0115	
MLE of Mean	0.00865	
MLE of Standard Deviation	0.00997	
nu star	156.5	
Approximate Chi Square Value (.05)	128.6	**Nonparametric Statistics**
Adjusted Level of Significance	0.0477	95% CLT UCL 0.0113
Adjusted Chi Square Value	128.2	95% Jackknife UCL 0.0113
		95% Standard Bootstrap UCL 0.0112
Anderson-Darling Test Statistic	9.757	95% Bootstrap-t UCL 0.0125
Anderson-Darling 5% Critical Value	0.794	95% Hall's Bootstrap UCL 0.0132
Kolmogorov-Smirnov Test Statistic	0.266	95% Percentile Bootstrap UCL 0.0114
Kolmogorov-Smirnov 5% Critical Value	0.0918	95% BCA Bootstrap UCL 0.0122
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0157
		97.5% Chebyshev(Mean, Sd) UCL 0.0187
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0247
95% Approximate Gamma UCL	0.0105	
95% Adjusted Gamma UCL	0.0106	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0157

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (rro)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	26

Raw Statistics		Log-transformed Statistics	
Minimum	6.35	Minimum of Log Data	1.848
Maximum	8450	Maximum of Log Data	9.042
Mean	445.1	Mean of log Data	4.15
Median	53.75	SD of log Data	1.626
SD	1647		
Coefficient of Variation	3.701		
Skewness	4.962		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.274	Shapiro Wilk Test Statistic	0.926
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	996.9	95% H-UCL	720.6
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	589.6
95% Adjusted-CLT UCL (Chen-1995)	1312	97.5% Chebyshev (MVUE) UCL	752
95% Modified-t UCL (Johnson-1978)	1049	99% Chebyshev (MVUE) UCL	1071

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.332	**Data appear Lognormal at 5% Significance Level**	
Theta Star	1342		
MLE of Mean	445.1		
MLE of Standard Deviation	772.9		
nu star	17.24		
Approximate Chi Square Value (.05)	8.846	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	976.5
Adjusted Chi Square Value	8.45	95% Jackknife UCL	996.9
		95% Standard Bootstrap UCL	966.4
Anderson-Darling Test Statistic	3.288	95% Bootstrap-t UCL	6305
Anderson-Darling 5% Critical Value	0.842	95% Hall's Bootstrap UCL	4097
Kolmogorov-Smirnov Test Statistic	0.322	95% Percentile Bootstrap UCL	1071
Kolmogorov-Smirnov 5% Critical Value	0.185	95% BCA Bootstrap UCL	1455
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1853
		97.5% Chebyshev(Mean, Sd) UCL	2463
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	3659
95% Approximate Gamma UCL	867.6		
95% Adjusted Gamma UCL	908.3		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	1853

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (selenium)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	24

Raw Statistics		Log-transformed Statistics	
Minimum	0.138	Minimum of Log Data	-1.981
Maximum	0.625	Maximum of Log Data	-0.47
Mean	0.251	Mean of log Data	-1.49
Median	0.196	SD of log Data	0.448
SD	0.131		
Coefficient of Variation	0.522		
Skewness	1.478		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.801	Shapiro Wilk Test Statistic	0.878
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.295	95% H-UCL	0.296
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.346
95% Adjusted-CLT UCL (Chen-1995)	0.301	97.5% Chebyshev (MVUE) UCL	0.389
95% Modified-t UCL (Johnson-1978)	0.296	99% Chebyshev (MVUE) UCL	0.472

Gamma Distribution Test		Data Distribution
k star (bias corrected)	4.337	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0578	
MLE of Mean	0.251	
MLE of Standard Deviation	0.12	
nu star	225.5	
Approximate Chi Square Value (.05)	191.7	**Nonparametric Statistics**
Adjusted Level of Significance	0.0398	95% CLT UCL 0.293
Adjusted Chi Square Value	189.7	95% Jackknife UCL 0.295
		95% Standard Bootstrap UCL 0.293
Anderson-Darling Test Statistic	1.38	95% Bootstrap-t UCL 0.308
Anderson-Darling 5% Critical Value	0.747	95% Hall's Bootstrap UCL 0.301
Kolmogorov-Smirnov Test Statistic	0.197	95% Percentile Bootstrap UCL 0.294
Kolmogorov-Smirnov 5% Critical Value	0.172	95% BCA Bootstrap UCL 0.299
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.363
		97.5% Chebyshev(Mean, Sd) UCL 0.411
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.506
95% Approximate Gamma UCL	0.295	
95% Adjusted Gamma UCL	0.298	

Potential UCL to Use	
Use 95% Student's-t UCL	0.295
or 95% Modified-t UCL	0.296

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (sulfolane)

General Statistics

Number of Valid Observations	99	Number of Distinct Observations	49

Raw Statistics		Log-transformed Statistics	
Minimum	0.00313	Minimum of Log Data	-5.767
Maximum	0.0377	Maximum of Log Data	-3.278
Mean	0.00449	Mean of log Data	-5.562
Median	0.00326	SD of log Data	0.433
SD	0.00444		
Coefficient of Variation	0.99		
Skewness	5.678		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.399	Lilliefors Test Statistic	0.339
Lilliefors Critical Value	0.089	Lilliefors Critical Value	0.089
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.00523	95% H-UCL	0.00457
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00505
95% Adjusted-CLT UCL (Chen-1995)	0.00549	97.5% Chebyshev (MVUE) UCL	0.00541
95% Modified-t UCL (Johnson-1978)	0.00527	99% Chebyshev (MVUE) UCL	0.00611

Gamma Distribution Test		Data Distribution
k star (bias corrected)	3.289	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.00136	
MLE of Mean	0.00449	
MLE of Standard Deviation	0.00247	
nu star	651.3	
Approximate Chi Square Value (.05)	593.1	**Nonparametric Statistics**
Adjusted Level of Significance	0.0476	95% CLT UCL 0.00522
Adjusted Chi Square Value	592.2	95% Jackknife UCL 0.00523
		95% Standard Bootstrap UCL 0.0052
Anderson-Darling Test Statistic	21.77	95% Bootstrap-t UCL 0.00597
Anderson-Darling 5% Critical Value	0.758	95% Hall's Bootstrap UCL 0.00829
Kolmogorov-Smirnov Test Statistic	0.376	95% Percentile Bootstrap UCL 0.0053
Kolmogorov-Smirnov 5% Critical Value	0.0904	95% BCA Bootstrap UCL 0.00564
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.00643
		97.5% Chebyshev(Mean, Sd) UCL 0.00727
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.00893
95% Approximate Gamma UCL	0.00493	
95% Adjusted Gamma UCL	0.00493	

Potential UCL to Use	
Use 95% Student's-t UCL	0.00523
or 95% Modified-t UCL	0.00527

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (tert-butylbenzene)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	23

Raw Statistics		Log-transformed Statistics	
Minimum	0.00505	Minimum of Log Data	-5.288
Maximum	0.0158	Maximum of Log Data	-4.148
Mean	0.00916	Mean of log Data	-4.762
Median	0.00753	SD of log Data	0.375
SD	0.00356		
Coefficient of Variation	0.389		
Skewness	0.666		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.868	Shapiro Wilk Test Statistic	0.901
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0104	95% H-UCL	0.0105
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0121
95% Adjusted-CLT UCL (Chen-1995)	0.0104	97.5% Chebyshev (MVUE) UCL	0.0134
95% Modified-t UCL (Johnson-1978)	0.0104	99% Chebyshev (MVUE) UCL	0.016

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	6.556	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0014		
MLE of Mean	0.00916		
MLE of Standard Deviation	0.00358		
nu star	340.9		
Approximate Chi Square Value (.05)	299.1	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0398	95% CLT UCL	0.0103
Adjusted Chi Square Value	296.5	95% Jackknife UCL	0.0104
		95% Standard Bootstrap UCL	0.0103
Anderson-Darling Test Statistic	1.09	95% Bootstrap-t UCL	0.0104
Anderson-Darling 5% Critical Value	0.745	95% Hall's Bootstrap UCL	0.0104
Kolmogorov-Smirnov Test Statistic	0.175	95% Percentile Bootstrap UCL	0.0103
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL	0.0104
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0122
		97.5% Chebyshev(Mean, Sd) UCL	0.0135
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0161
95% Approximate Gamma UCL	0.0104		
95% Adjusted Gamma UCL	0.0105		

Potential UCL to Use	
Use 95% Student's-t UCL	0.0104
or 95% Modified-t UCL	0.0104

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (toluene)

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	90

Raw Statistics		Log-transformed Statistics	
Minimum	0.0047	Minimum of Log Data	-5.36
Maximum	1.04	Maximum of Log Data	0.0392
Mean	0.0318	Mean of log Data	-4.434
Median	0.0098	SD of log Data	0.904
SD	0.116		
Coefficient of Variation	3.658		
Skewness	7.328		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.445	Lilliefors Test Statistic	0.232
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0507	95% H-UCL	0.0216
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0258
95% Adjusted-CLT UCL (Chen-1995)	0.0593	97.5% Chebyshev (MVUE) UCL	0.0293
95% Modified-t UCL (Johnson-1978)	0.0521	99% Chebyshev (MVUE) UCL	0.0361

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.612	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0519		
MLE of Mean	0.0318		
MLE of Standard Deviation	0.0406		
nu star	127.3		
Approximate Chi Square Value (.05)	102.3	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0477	95% CLT UCL	0.0505
Adjusted Chi Square Value	101.9	95% Jackknife UCL	0.0507
		95% Standard Bootstrap UCL	0.0493
Anderson-Darling Test Statistic	20.89	95% Bootstrap-t UCL	0.104
Anderson-Darling 5% Critical Value	0.807	95% Hall's Bootstrap UCL	0.118
Kolmogorov-Smirnov Test Statistic	0.377	95% Percentile Bootstrap UCL	0.053
Kolmogorov-Smirnov 5% Critical Value	0.0927	95% BCA Bootstrap UCL	0.0632
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0815
		97.5% Chebyshev(Mean, Sd) UCL	0.103
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.145
95% Approximate Gamma UCL	0.0396		
95% Adjusted Gamma UCL	0.0397		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0815

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (xylenes (total))

General Statistics

Number of Valid Observations	104	Number of Distinct Observations	95

Raw Statistics		Log-transformed Statistics	
Minimum	0.0138	Minimum of Log Data	-4.287
Maximum	10.3	Maximum of Log Data	2.332
Mean	0.244	Mean of log Data	-3.334
Median	0.024	SD of log Data	1.232
SD	1.159		
Std. Error of Mean	0.114		
Coefficient of Variation	4.757		
Skewness	7.376		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.456	Lilliefors Test Statistic	0.291
Lilliefors Critical Value	0.0869	Lilliefors Critical Value	0.0869
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.432	95% H-UCL	0.102
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.126
95% Adjusted-CLT UCL (Chen-1995)	0.518	97.5% Chebyshev (MVUE) UCL	0.148
95% Modified-t UCL (Johnson-1978)	0.446	99% Chebyshev (MVUE) UCL	0.191

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.346	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.704		
MLE of Mean	0.244		
MLE of Standard Deviation	0.414		
nu star	72		
Approximate Chi Square Value (.05)	53.46	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0477	95% CLT UCL	0.431
Adjusted Chi Square Value	53.24	95% Jackknife UCL	0.432
		95% Standard Bootstrap UCL	0.429
Anderson-Darling Test Statistic	26.34	95% Bootstrap-t UCL	0.989
Anderson-Darling 5% Critical Value	0.855	95% Hall's Bootstrap UCL	1.106
Kolmogorov-Smirnov Test Statistic	0.448	95% Percentile Bootstrap UCL	0.447
Kolmogorov-Smirnov 5% Critical Value	0.0954	95% BCA Bootstrap UCL	0.579
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.739
		97.5% Chebyshev(Mean, Sd) UCL	0.953
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.375
95% Approximate Gamma UCL	0.328		
95% Adjusted Gamma UCL	0.33		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.739

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (zinc)

General Statistics

Number of Valid Observations	26	Number of Distinct Observations	24

Raw Statistics		Log-transformed Statistics	
Minimum	20.9	Minimum of Log Data	3.04
Maximum	63.8	Maximum of Log Data	4.156
Mean	40.39	Mean of log Data	3.66
Median	36.65	SD of log Data	0.282
SD	11.54		
Coefficient of Variation	0.286		
Skewness	0.573		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.928	Shapiro Wilk Test Statistic	0.956
Shapiro Wilk Critical Value	0.92	Shapiro Wilk Critical Value	0.92
Data appear Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	44.25	95% H-UCL	44.79
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	50.26
95% Adjusted-CLT UCL (Chen-1995)	44.38	97.5% Chebyshev (MVUE) UCL	54.54
95% Modified-t UCL (Johnson-1978)	44.3	99% Chebyshev (MVUE) UCL	62.94

Gamma Distribution Test		Data Distribution
k star (bias corrected)	11.69	**Data appear Normal at 5% Significance Level**
Theta Star	3.456	
MLE of Mean	40.39	
MLE of Standard Deviation	11.81	
nu star	607.8	
Approximate Chi Square Value (.05)	551.6	**Nonparametric Statistics**
Adjusted Level of Significance	0.0398	95% CLT UCL 44.11
Adjusted Chi Square Value	548	95% Jackknife UCL 44.25
		95% Standard Bootstrap UCL 44.13
Anderson-Darling Test Statistic	0.614	95% Bootstrap-t UCL 44.72
Anderson-Darling 5% Critical Value	0.744	95% Hall's Bootstrap UCL 44.41
Kolmogorov-Smirnov Test Statistic	0.177	95% Percentile Bootstrap UCL 44.17
Kolmogorov-Smirnov 5% Critical Value	0.171	95% BCA Bootstrap UCL 44.04
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 50.25
		97.5% Chebyshev(Mean, Sd) UCL 54.52
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 62.9
95% Approximate Gamma UCL	44.5	
95% Adjusted Gamma UCL	44.79	

Potential UCL to Use	
Use 95% Student's-t UCL	44.25

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

General UCL Statistics for Data Sets with Non-Detects

User Selected Options

From File	MB_0-15 All Transposed.wst
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Result (1/2 DL for NDs) (1,1-dichloroethylene)

General Statistics

Number of Valid Observations	63	Number of Distinct Observations	54

Raw Statistics		Log-transformed Statistics	
Minimum	0.00431	Minimum of Log Data	-5.447
Maximum	0.68	Maximum of Log Data	-0.386
Mean	0.025	Mean of log Data	-4.532
Median	0.0082	SD of log Data	0.877
SD	0.0859		
Coefficient of Variation	3.432		
Skewness	7.388		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.432	Lilliefors Test Statistic	0.22
Lilliefors Critical Value	0.112	Lilliefors Critical Value	0.112
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.0431	95% H-UCL	0.0201
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0243
95% Adjusted-CLT UCL (Chen-1995)	0.0536	97.5% Chebyshev (MVUE) UCL	0.0281
95% Modified-t UCL (Johnson-1978)	0.0448	99% Chebyshev (MVUE) UCL	0.0354

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.69	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0363	
MLE of Mean	0.025	
MLE of Standard Deviation	0.0301	
nu star	86.96	
Approximate Chi Square Value (.05)	66.47	**Nonparametric Statistics**
Adjusted Level of Significance	0.0462	95% CLT UCL 0.0429
Adjusted Chi Square Value	66.05	95% Jackknife UCL 0.0431
		95% Standard Bootstrap UCL 0.0426
Anderson-Darling Test Statistic	10.99	95% Bootstrap-t UCL 0.109
Anderson-Darling 5% Critical Value	0.796	95% Hall's Bootstrap UCL 0.101
Kolmogorov-Smirnov Test Statistic	0.37	95% Percentile Bootstrap UCL 0.0458
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.0581
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0722
		97.5% Chebyshev(Mean, Sd) UCL 0.0927
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.133
95% Approximate Gamma UCL	0.0328	
95% Adjusted Gamma UCL	0.033	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0722

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (1,2,4-trimethylbenzene)

General Statistics

Number of Valid Observations	90	Number of Distinct Observations	84

Raw Statistics		Log-transformed Statistics	
Minimum	0.0062	Minimum of Log Data	-5.083
Maximum	205	Maximum of Log Data	5.323
Mean	8.812	Mean of log Data	-2.376
Median	0.023	SD of log Data	2.968
SD	28.77		
Coefficient of Variation	3.265		
Skewness	4.913		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.405	Lilliefors Test Statistic	0.328
Lilliefors Critical Value	0.0934	Lilliefors Critical Value	0.0934
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	13.85	95% H-UCL	33.02
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	20.86
95% Adjusted-CLT UCL (Chen-1995)	15.48	97.5% Chebyshev (MVUE) UCL	27.28
95% Modified-t UCL (Johnson-1978)	14.11	99% Chebyshev (MVUE) UCL	39.9

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.168	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	52.41	
MLE of Mean	8.812	
MLE of Standard Deviation	21.49	
nu star	30.27	
Approximate Chi Square Value (.05)	18.7	**Nonparametric Statistics**
Adjusted Level of Significance	0.0473	95% CLT UCL 13.8
Adjusted Chi Square Value	18.56	95% Jackknife UCL 13.85
		95% Standard Bootstrap UCL 13.69
Anderson-Darling Test Statistic	16.66	95% Bootstrap-t UCL 18.32
Anderson-Darling 5% Critical Value	0.945	95% Hall's Bootstrap UCL 16.13
Kolmogorov-Smirnov Test Statistic	0.396	95% Percentile Bootstrap UCL 14.24
Kolmogorov-Smirnov 5% Critical Value	0.106	95% BCA Bootstrap UCL 15.94
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 22.03
		97.5% Chebyshev(Mean, Sd) UCL 27.75
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 38.99
95% Approximate Gamma UCL	14.26	
95% Adjusted Gamma UCL	14.37	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	22.03

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (1,2-dichlorobenzene)

General Statistics

Number of Valid Observations	63	Number of Distinct Observations	38

Raw Statistics		Log-transformed Statistics	
Minimum	0.06	Minimum of Log Data	-2.813
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.221	Mean of log Data	-2.283
Median	0.084	SD of log Data	0.753
SD	0.668		
Coefficient of Variation	3.024		
Skewness	5.411		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.426
Lilliefors Critical Value	0.112	Lilliefors Critical Value	0.112
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.362	95% H-UCL	0.165
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.197
95% Adjusted-CLT UCL (Chen-1995)	0.421	97.5% Chebyshev (MVUE) UCL	0.223
95% Modified-t UCL (Johnson-1978)	0.371	99% Chebyshev (MVUE) UCL	0.276

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.745	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.297	
MLE of Mean	0.221	
MLE of Standard Deviation	0.256	
nu star	93.9	
Approximate Chi Square Value (.05)	72.55	**Nonparametric Statistics**
Adjusted Level of Significance	0.0462	95% CLT UCL 0.36
Adjusted Chi Square Value	72.11	95% Jackknife UCL 0.362
		95% Standard Bootstrap UCL 0.361
Anderson-Darling Test Statistic	19.88	95% Bootstrap-t UCL 1.182
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.433
Kolmogorov-Smirnov Test Statistic	0.511	95% Percentile Bootstrap UCL 0.378
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.438
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.588
		97.5% Chebyshev(Mean, Sd) UCL 0.747
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.059
95% Approximate Gamma UCL	0.286	
95% Adjusted Gamma UCL	0.288	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.588

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (1,3,5-trimethylbenzene)

General Statistics

Number of Valid Observations	89	Number of Distinct Observations	81

Raw Statistics		Log-transformed Statistics	
Minimum	0.00431	Minimum of Log Data	-5.447
Maximum	81.1	Maximum of Log Data	4.396
Mean	3.223	Mean of log Data	-3.116
Median	0.0122	SD of log Data	2.793
SD	11.01		
Coefficient of Variation	3.416		
Skewness	5.193		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.407	Lilliefors Test Statistic	0.323
Lilliefors Critical Value	0.0939	Lilliefors Critical Value	0.0939
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	5.163	95% H-UCL	8.205
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	5.961
95% Adjusted-CLT UCL (Chen-1995)	5.829	97.5% Chebyshev (MVUE) UCL	7.757
95% Modified-t UCL (Johnson-1978)	5.27	99% Chebyshev (MVUE) UCL	11.29

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.177	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	18.23		
MLE of Mean	3.223		
MLE of Standard Deviation	7.665		
nu star	31.47		
Approximate Chi Square Value (.05)	19.65	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0473	95% CLT UCL	5.143
Adjusted Chi Square Value	19.5	95% Jackknife UCL	5.163
		95% Standard Bootstrap UCL	5.116
Anderson-Darling Test Statistic	16.48	95% Bootstrap-t UCL	6.966
Anderson-Darling 5% Critical Value	0.936	95% Hall's Bootstrap UCL	6.805
Kolmogorov-Smirnov Test Statistic	0.401	95% Percentile Bootstrap UCL	5.404
Kolmogorov-Smirnov 5% Critical Value	0.106	95% BCA Bootstrap UCL	6.001
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	8.31
		97.5% Chebyshev(Mean, Sd) UCL	10.51
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	14.84
95% Approximate Gamma UCL	5.161		
95% Adjusted Gamma UCL	5.202		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	8.31

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (1,3-dichlorobenzene)

General Statistics

Number of Valid Observations	63	Number of Distinct Observations	38

Raw Statistics		Log-transformed Statistics	
Minimum	0.06	Minimum of Log Data	-2.813
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.221	Mean of log Data	-2.283
Median	0.084	SD of log Data	0.753
SD	0.668		
Coefficient of Variation	3.024		
Skewness	5.411		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.426
Lilliefors Critical Value	0.112	Lilliefors Critical Value	0.112
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.362	95% H-UCL	0.165
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.197
95% Adjusted-CLT UCL (Chen-1995)	0.421	97.5% Chebyshev (MVUE) UCL	0.223
95% Modified-t UCL (Johnson-1978)	0.371	99% Chebyshev (MVUE) UCL	0.276

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.745	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.297	
MLE of Mean	0.221	
MLE of Standard Deviation	0.256	
nu star	93.9	
Approximate Chi Square Value (.05)	72.55	**Nonparametric Statistics**
Adjusted Level of Significance	0.0462	95% CLT UCL 0.36
Adjusted Chi Square Value	72.11	95% Jackknife UCL 0.362
		95% Standard Bootstrap UCL 0.358
Anderson-Darling Test Statistic	19.88	95% Bootstrap-t UCL 1.139
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.435
Kolmogorov-Smirnov Test Statistic	0.511	95% Percentile Bootstrap UCL 0.371
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.45
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.588
		97.5% Chebyshev(Mean, Sd) UCL 0.747
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.059
95% Approximate Gamma UCL	0.286	
95% Adjusted Gamma UCL	0.288	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.588

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (1-methylnaphthalene)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	191

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	88.5	Maximum of Log Data	4.483
Mean	2.5	Mean of log Data	-3.896
Median	0.00458	SD of log Data	3.27
SD	8.216		
Coefficient of Variation	3.287		
Skewness	5.862		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.391	Lilliefors Test Statistic	0.223
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	3.3	95% H-UCL	10.45
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	10.99
95% Adjusted-CLT UCL (Chen-1995)	3.477	97.5% Chebyshev (MVUE) UCL	14.09
95% Modified-t UCL (Johnson-1978)	3.328	99% Chebyshev (MVUE) UCL	20.19

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.159	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	15.71	
MLE of Mean	2.5	
MLE of Standard Deviation	6.266	
nu star	91.33	
Approximate Chi Square Value (.05)	70.3	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 3.297
Adjusted Chi Square Value	70.2	95% Jackknife UCL 3.3
		95% Standard Bootstrap UCL 3.292
Anderson-Darling Test Statistic	41.58	95% Bootstrap-t UCL 3.571
Anderson-Darling 5% Critical Value	1.022	95% Hall's Bootstrap UCL 3.683
Kolmogorov-Smirnov Test Statistic	0.312	95% Percentile Bootstrap UCL 3.363
Kolmogorov-Smirnov 5% Critical Value	0.0616	95% BCA Bootstrap UCL 3.563
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 4.614
		97.5% Chebyshev(Mean, Sd) UCL 5.528
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 7.325
95% Approximate Gamma UCL	3.248	
95% Adjusted Gamma UCL	3.252	

Potential UCL to Use — Use 95% Chebyshev (Mean, Sd) UCL 4.614

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2,4,6-trichlorophenol)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.301	
MLE of Mean	0.224	
MLE of Standard Deviation	0.26	
nu star	92.03	
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL 0.366
		95% Standard Bootstrap UCL 0.363
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL 1.165
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.458
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL 0.387
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.456
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.596
		97.5% Chebyshev(Mean, Sd) UCL 0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.075
95% Approximate Gamma UCL	0.29	
95% Adjusted Gamma UCL	0.292	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2,4-dichlorophenol)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.301	
MLE of Mean	0.224	
MLE of Standard Deviation	0.26	
nu star	92.03	
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL 0.366
		95% Standard Bootstrap UCL 0.365
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL 1.17
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.463
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL 0.38
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.459
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.596
		97.5% Chebyshev(Mean, Sd) UCL 0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.075
95% Approximate Gamma UCL	0.29	
95% Adjusted Gamma UCL	0.292	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2,4-dimethylphenol)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.301	
MLE of Mean	0.224	
MLE of Standard Deviation	0.26	
nu star	92.03	
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL 0.366
		95% Standard Bootstrap UCL 0.36
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL 1.161
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.46
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL 0.375
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.439
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.596
		97.5% Chebyshev(Mean, Sd) UCL 0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.075
95% Approximate Gamma UCL	0.29	
95% Adjusted Gamma UCL	0.292	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2,4-dinitrophenol)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	34

Raw Statistics		Log-transformed Statistics	
Minimum	0.945	Minimum of Log Data	-0.0566
Maximum	51	Maximum of Log Data	3.932
Mean	2.69	Mean of log Data	0.215
Median	1.01	SD of log Data	0.755
SD	8.092		
Coefficient of Variation	3.008		
Skewness	5.363		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.431
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	4.407	95% H-UCL	2.011
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	2.402
95% Adjusted-CLT UCL (Chen-1995)	5.129	97.5% Chebyshev (MVUE) UCL	2.732
95% Modified-t UCL (Johnson-1978)	4.523	99% Chebyshev (MVUE) UCL	3.381

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.743	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	3.619	
MLE of Mean	2.69	
MLE of Standard Deviation	3.12	
nu star	92.17	
Approximate Chi Square Value (.05)	71.04	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 4.381
Adjusted Chi Square Value	70.59	95% Jackknife UCL 4.407
		95% Standard Bootstrap UCL 4.331
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL 14
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 17.6
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL 4.622
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 5.258
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 7.17
		97.5% Chebyshev(Mean, Sd) UCL 9.108
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 12.92
95% Approximate Gamma UCL	3.491	
95% Adjusted Gamma UCL	3.513	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	7.17

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2,4-dinitrotoluene)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.301	
MLE of Mean	0.224	
MLE of Standard Deviation	0.26	
nu star	92.03	
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL 0.366
		95% Standard Bootstrap UCL 0.363
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL 1.159
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.461
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL 0.371
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.444
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.596
		97.5% Chebyshev(Mean, Sd) UCL 0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.075
95% Approximate Gamma UCL	0.29	
95% Adjusted Gamma UCL	0.292	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2,6-dinitrotoluene)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281
Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.301		
MLE of Mean	0.224		
MLE of Standard Deviation	0.26		
nu star	92.03		
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0461	95% CLT UCL	0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL	0.366
		95% Standard Bootstrap UCL	0.36
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL	1.157
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL	1.444
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL	0.366
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL	0.446
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.596
		97.5% Chebyshev(Mean, Sd) UCL	0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.075
95% Approximate Gamma UCL	0.29		
95% Adjusted Gamma UCL	0.292		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2-chlorophenol)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.301	
MLE of Mean	0.224	
MLE of Standard Deviation	0.26	
nu star	92.03	
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL 0.366
		95% Standard Bootstrap UCL 0.363
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL 1.465
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.456
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL 0.375
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.436
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.596
		97.5% Chebyshev(Mean, Sd) UCL 0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.075
95% Approximate Gamma UCL	0.29	
95% Adjusted Gamma UCL	0.292	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2-methylnaphthalene)

General Statistics

Number of Valid Observations	314	Number of Distinct Observations	221

Raw Statistics		Log-transformed Statistics	
Minimum	0.00152	Minimum of Log Data	-6.489
Maximum	240	Maximum of Log Data	5.481
Mean	4.295	Mean of log Data	-3.531
Median	0.00763	SD of log Data	3.421
SD	17.43		
Coefficient of Variation	4.059		
Skewness	9.233		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.403	Lilliefors Test Statistic	0.207
Lilliefors Critical Value	0.05	Lilliefors Critical Value	0.05
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	5.918	95% H-UCL	25.48
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	26.55
95% Adjusted-CLT UCL (Chen-1995)	6.461	97.5% Chebyshev (MVUE) UCL	34.15
95% Modified-t UCL (Johnson-1978)	6.004	99% Chebyshev (MVUE) UCL	49.06

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.154	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	27.86	
MLE of Mean	4.295	
MLE of Standard Deviation	10.94	
nu star	96.83	
Approximate Chi Square Value (.05)	75.13	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 5.913
Adjusted Chi Square Value	75.05	95% Jackknife UCL 5.918
		95% Standard Bootstrap UCL 5.947
Anderson-Darling Test Statistic	39.86	95% Bootstrap-t UCL 6.822
Anderson-Darling 5% Critical Value	1.044	95% Hall's Bootstrap UCL 12.49
Kolmogorov-Smirnov Test Statistic	0.28	95% Percentile Bootstrap UCL 5.981
Kolmogorov-Smirnov 5% Critical Value	0.0592	95% BCA Bootstrap UCL 6.754
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 8.584
		97.5% Chebyshev(Mean, Sd) UCL 10.44
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 14.08
95% Approximate Gamma UCL	5.536	
95% Adjusted Gamma UCL	5.542	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	8.584

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (2-methylphenol (o-cresol))

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics

Minimum	0.0785
Maximum	4.25
Mean	0.224
Median	0.084
SD	0.673
Coefficient of Variation	3.012
Skewness	5.366

Log-transformed Statistics

Minimum of Log Data	-2.545
Maximum of Log Data	1.447
Mean of log Data	-2.274
SD of log Data	0.756

Relevant UCL Statistics

Normal Distribution Test

Lilliefors Test Statistic	0.506
Lilliefors Critical Value	0.113

Data not Normal at 5% Significance Level

Assuming Normal Distribution

95% Student's-t UCL	0.366

95% UCLs (Adjusted for Skewness)

95% Adjusted-CLT UCL (Chen-1995)	0.427
95% Modified-t UCL (Johnson-1978)	0.376

Gamma Distribution Test

k star (bias corrected)	0.742
Theta Star	0.301
MLE of Mean	0.224
MLE of Standard Deviation	0.26
nu star	92.03
Approximate Chi Square Value (.05)	70.91
Adjusted Level of Significance	0.0461
Adjusted Chi Square Value	70.47
Anderson-Darling Test Statistic	19.74
Anderson-Darling 5% Critical Value	0.791
Kolmogorov-Smirnov Test Statistic	0.513
Kolmogorov-Smirnov 5% Critical Value	0.117

Data not Gamma Distributed at 5% Significance Level

Assuming Gamma Distribution

95% Approximate Gamma UCL	0.29
95% Adjusted Gamma UCL	0.292

Potential UCL to Use

Use 95% Chebyshev (Mean, Sd) UCL 0.596

Lognormal Distribution Test

Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113

Data not Lognormal at 5% Significance Level

Assuming Lognormal Distribution

95% H-UCL	0.167
95% Chebyshev (MVUE) UCL	0.2
97.5% Chebyshev (MVUE) UCL	0.227
99% Chebyshev (MVUE) UCL	0.281

Data Distribution

Data do not follow a Discernable Distribution (0.05)

Nonparametric Statistics

95% CLT UCL	0.364
95% Jackknife UCL	0.366
95% Standard Bootstrap UCL	0.365
95% Bootstrap-t UCL	1.167
95% Hall's Bootstrap UCL	1.465
95% Percentile Bootstrap UCL	0.378
95% BCA Bootstrap UCL	0.479
95% Chebyshev(Mean, Sd) UCL	0.596
97.5% Chebyshev(Mean, Sd) UCL	0.758
99% Chebyshev(Mean, Sd) UCL	1.075

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (3&4-methylphenol (p&m-cresol))

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	45

Raw Statistics		Log-transformed Statistics	
Minimum	0.312	Minimum of Log Data	-1.165
Maximum	16.9	Maximum of Log Data	2.827
Mean	0.888	Mean of log Data	-0.894
Median	0.334	SD of log Data	0.756
SD	2.675		
Coefficient of Variation	3.011		
Skewness	5.37		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.432
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	1.456	95% H-UCL	0.663
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.793
95% Adjusted-CLT UCL (Chen-1995)	1.695	97.5% Chebyshev (MVUE) UCL	0.902
95% Modified-t UCL (Johnson-1978)	1.494	99% Chebyshev (MVUE) UCL	1.116

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.743	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	1.196	
MLE of Mean	0.888	
MLE of Standard Deviation	1.031	
nu star	92.09	
Approximate Chi Square Value (.05)	70.96	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 1.447
Adjusted Chi Square Value	70.52	95% Jackknife UCL 1.456
		95% Standard Bootstrap UCL 1.44
Anderson-Darling Test Statistic	19.75	95% Bootstrap-t UCL 4.64
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 5.84
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL 1.502
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 1.749
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 2.369
		97.5% Chebyshev(Mean, Sd) UCL 3.01
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 4.268
95% Approximate Gamma UCL	1.153	
95% Adjusted Gamma UCL	1.16	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	2.369

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (3,3-dichlorobenzidine)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.301	
MLE of Mean	0.224	
MLE of Standard Deviation	0.26	
nu star	92.03	
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL 0.366
		95% Standard Bootstrap UCL 0.362
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL 1.161
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.464
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL 0.364
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.443
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.596
		97.5% Chebyshev(Mean, Sd) UCL 0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.075
95% Approximate Gamma UCL	0.29	
95% Adjusted Gamma UCL	0.292	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (4-chloroaniline)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		Log-transformed Statistics	
Minimum	0.151	Minimum of Log Data	-1.89
Maximum	8.15	Maximum of Log Data	2.098
Mean	0.429	Mean of log Data	-1.621
Median	0.162	SD of log Data	0.755
SD	1.293		
Coefficient of Variation	3.01		
Skewness	5.364		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.432
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.704	95% H-UCL	0.321
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.383
95% Adjusted-CLT UCL (Chen-1995)	0.819	97.5% Chebyshev (MVUE) UCL	0.436
95% Modified-t UCL (Johnson-1978)	0.722	99% Chebyshev (MVUE) UCL	0.539

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.743	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.578	
MLE of Mean	0.429	
MLE of Standard Deviation	0.498	
nu star	92.12	
Approximate Chi Square Value (.05)	70.99	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.7
Adjusted Chi Square Value	70.55	95% Jackknife UCL 0.704
		95% Standard Bootstrap UCL 0.697
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL 2.237
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 2.793
Kolmogorov-Smirnov Test Statistic	0.514	95% Percentile Bootstrap UCL 0.698
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.847
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 1.145
		97.5% Chebyshev(Mean, Sd) UCL 1.455
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 2.063
95% Approximate Gamma UCL	0.557	
95% Adjusted Gamma UCL	0.561	

Potential UCL to Use		
		Use 95% Chebyshev (Mean, Sd) UCL 1.145

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (4-isopropyltoluene (p-cymene))

General Statistics

Number of Valid Observations	90	Number of Distinct Observations	80

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.00431	Minimum of Log Data	-5.447
Maximum	20.2	Maximum of Log Data	3.006
Mean	0.799	Mean of log Data	-3.493
Median	0.011	SD of log Data	2.279
SD	2.669		
Coefficient of Variation	3.339		
Skewness	5.348		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.401	Lilliefors Test Statistic	0.347
Lilliefors Critical Value	0.0934	Lilliefors Critical Value	0.0934
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	1.267	95% H-UCL	1.01
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.012
95% Adjusted-CLT UCL (Chen-1995)	1.432	97.5% Chebyshev (MVUE) UCL	1.29
95% Modified-t UCL (Johnson-1978)	1.293	99% Chebyshev (MVUE) UCL	1.835

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	0.222	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	3.608	
MLE of Mean	0.799	
MLE of Standard Deviation	1.698	
nu star	39.88	
Approximate Chi Square Value (.05)	26.41	**Nonparametric Statistics**
Adjusted Level of Significance	0.0473	95% CLT UCL 1.262
Adjusted Chi Square Value	26.23	95% Jackknife UCL 1.267
		95% Standard Bootstrap UCL 1.262
Anderson-Darling Test Statistic	16.87	95% Bootstrap-t UCL 1.722
Anderson-Darling 5% Critical Value	0.902	95% Hall's Bootstrap UCL 1.792
Kolmogorov-Smirnov Test Statistic	0.424	95% Percentile Bootstrap UCL 1.294
Kolmogorov-Smirnov 5% Critical Value	0.104	95% BCA Bootstrap UCL 1.428
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 2.026
		97.5% Chebyshev(Mean, Sd) UCL 2.556
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 3.599
95% Approximate Gamma UCL	1.207	
95% Adjusted Gamma UCL	1.215	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	2.026

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (acenaphthene)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	113

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	0.67	Maximum of Log Data	-0.4
Mean	0.0192	Mean of log Data	-5.479
Median	0.00178	SD of log Data	1.416
SD	0.0606		
Coefficient of Variation	3.163		
Skewness	6.693		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.385	Lilliefors Test Statistic	0.331
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0251	95% H-UCL	0.014
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.017
95% Adjusted-CLT UCL (Chen-1995)	0.0266	97.5% Chebyshev (MVUE) UCL	0.0195
95% Modified-t UCL (Johnson-1978)	0.0253	99% Chebyshev (MVUE) UCL	0.0244

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.425	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0451	
MLE of Mean	0.0192	
MLE of Standard Deviation	0.0294	
nu star	243.9	
Approximate Chi Square Value (.05)	208.8	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 0.0251
Adjusted Chi Square Value	208.6	95% Jackknife UCL 0.0251
		95% Standard Bootstrap UCL 0.0251
Anderson-Darling Test Statistic	44.09	95% Bootstrap-t UCL 0.0272
Anderson-Darling 5% Critical Value	0.839	95% Hall's Bootstrap UCL 0.0294
Kolmogorov-Smirnov Test Statistic	0.337	95% Percentile Bootstrap UCL 0.0256
Kolmogorov-Smirnov 5% Critical Value	0.0572	95% BCA Bootstrap UCL 0.0269
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0348
		97.5% Chebyshev(Mean, Sd) UCL 0.0415
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0548
95% Approximate Gamma UCL	0.0224	
95% Adjusted Gamma UCL	0.0224	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0348

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (acenaphthylene)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	114

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	0.67	Maximum of Log Data	-0.4
Mean	0.0192	Mean of log Data	-5.478
Median	0.00178	SD of log Data	1.416
SD	0.0606		
Coefficient of Variation	3.161		
Skewness	6.693		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.385	Lilliefors Test Statistic	0.332
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0251	95% H-UCL	0.0141
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.017
95% Adjusted-CLT UCL (Chen-1995)	0.0266	97.5% Chebyshev (MVUE) UCL	0.0195
95% Modified-t UCL (Johnson-1978)	0.0253	99% Chebyshev (MVUE) UCL	0.0244

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.425	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0451	
MLE of Mean	0.0192	
MLE of Standard Deviation	0.0294	
nu star	244	
Approximate Chi Square Value (.05)	208.8	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 0.0251
Adjusted Chi Square Value	208.7	95% Jackknife UCL 0.0251
		95% Standard Bootstrap UCL 0.025
Anderson-Darling Test Statistic	44	95% Bootstrap-t UCL 0.0274
Anderson-Darling 5% Critical Value	0.839	95% Hall's Bootstrap UCL 0.0282
Kolmogorov-Smirnov Test Statistic	0.337	95% Percentile Bootstrap UCL 0.0253
Kolmogorov-Smirnov 5% Critical Value	0.0572	95% BCA Bootstrap UCL 0.0274
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0348
		97.5% Chebyshev(Mean, Sd) UCL 0.0415
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0548
95% Approximate Gamma UCL	0.0224	
95% Adjusted Gamma UCL	0.0224	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0348

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (anthracene)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	127

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	0.67	Maximum of Log Data	-0.4
Mean	0.0232	Mean of log Data	-5.394
Median	0.00181	SD of log Data	1.507
SD	0.0688		
Coefficient of Variation	2.96		
Skewness	5.547		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.376	Lilliefors Test Statistic	0.322
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0299	95% H-UCL	0.0178
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0218
95% Adjusted-CLT UCL (Chen-1995)	0.0313	97.5% Chebyshev (MVUE) UCL	0.0252
95% Modified-t UCL (Johnson-1978)	0.0302	99% Chebyshev (MVUE) UCL	0.0318

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.401	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.058	
MLE of Mean	0.0232	
MLE of Standard Deviation	0.0367	
nu star	230.1	
Approximate Chi Square Value (.05)	196	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 0.0299
Adjusted Chi Square Value	195.8	95% Jackknife UCL 0.0299
		95% Standard Bootstrap UCL 0.0298
Anderson-Darling Test Statistic	42.49	95% Bootstrap-t UCL 0.0324
Anderson-Darling 5% Critical Value	0.845	95% Hall's Bootstrap UCL 0.0321
Kolmogorov-Smirnov Test Statistic	0.328	95% Percentile Bootstrap UCL 0.0303
Kolmogorov-Smirnov 5% Critical Value	0.0574	95% BCA Bootstrap UCL 0.0319
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0409
		97.5% Chebyshev(Mean, Sd) UCL 0.0486
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0636
95% Approximate Gamma UCL	0.0273	
95% Adjusted Gamma UCL	0.0273	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0409

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (antimony)

General Statistics

Number of Valid Observations	69	Number of Distinct Observations	69

Raw Statistics		Log-transformed Statistics	
Minimum	0.0309	Minimum of Log Data	-3.477
Maximum	0.447	Maximum of Log Data	-0.806
Mean	0.116	Mean of log Data	-2.321
Median	0.0911	SD of log Data	0.564
SD	0.0785		
Coefficient of Variation	0.675		
Skewness	2.185		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.155	Lilliefors Test Statistic	0.0687
Lilliefors Critical Value	0.107	Lilliefors Critical Value	0.107
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.132	95% H-UCL	0.131
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.151
95% Adjusted-CLT UCL (Chen-1995)	0.134	97.5% Chebyshev (MVUE) UCL	0.167
95% Modified-t UCL (Johnson-1978)	0.132	99% Chebyshev (MVUE) UCL	0.197

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	2.994	**Data Follow Appr. Gamma Distribution at 5% Significance Level**	
Theta Star	0.0388		
MLE of Mean	0.116		
MLE of Standard Deviation	0.0672		
nu star	413.1		
Approximate Chi Square Value (.05)	367	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0465	95% CLT UCL	0.132
Adjusted Chi Square Value	366.1	95% Jackknife UCL	0.132
		95% Standard Bootstrap UCL	0.132
Anderson-Darling Test Statistic	1.078	95% Bootstrap-t UCL	0.135
Anderson-Darling 5% Critical Value	0.757	95% Hall's Bootstrap UCL	0.137
Kolmogorov-Smirnov Test Statistic	0.1	95% Percentile Bootstrap UCL	0.132
Kolmogorov-Smirnov 5% Critical Value	0.108	95% BCA Bootstrap UCL	0.135
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.157
		97.5% Chebyshev(Mean, Sd) UCL	0.175
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.21
95% Approximate Gamma UCL	0.131		
95% Adjusted Gamma UCL	0.131		

Potential UCL to Use	
Use 95% Approximate Gamma UCL	0.131

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (arsenic)

General Statistics

Number of Valid Observations	69	Number of Distinct Observations	61

Raw Statistics		Log-transformed Statistics	
Minimum	2.16	Minimum of Log Data	0.77
Maximum	17.6	Maximum of Log Data	2.868
Mean	5.525	Mean of log Data	1.562
Median	4.18	SD of log Data	0.523
SD	3.406		
Coefficient of Variation	0.616		
Skewness	1.711		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.201	Lilliefors Test Statistic	0.109
Lilliefors Critical Value	0.107	Lilliefors Critical Value	0.107
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	6.209	95% H-UCL	6.161
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	7.039
95% Adjusted-CLT UCL (Chen-1995)	6.29	97.5% Chebyshev (MVUE) UCL	7.724
95% Modified-t UCL (Johnson-1978)	6.223	99% Chebyshev (MVUE) UCL	9.071

Gamma Distribution Test		Data Distribution
k star (bias corrected)	3.403	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	1.623	
MLE of Mean	5.525	
MLE of Standard Deviation	2.995	
nu star	469.7	
Approximate Chi Square Value (.05)	420.4	**Nonparametric Statistics**
Adjusted Level of Significance	0.0465	95% CLT UCL 6.2
Adjusted Chi Square Value	419.4	95% Jackknife UCL 6.209
		95% Standard Bootstrap UCL 6.226
Anderson-Darling Test Statistic	1.852	95% Bootstrap-t UCL 6.299
Anderson-Darling 5% Critical Value	0.756	95% Hall's Bootstrap UCL 6.313
Kolmogorov-Smirnov Test Statistic	0.146	95% Percentile Bootstrap UCL 6.19
Kolmogorov-Smirnov 5% Critical Value	0.108	95% BCA Bootstrap UCL 6.229
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 7.313
		97.5% Chebyshev(Mean, Sd) UCL 8.086
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 9.605
95% Approximate Gamma UCL	6.172	
95% Adjusted Gamma UCL	6.187	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	7.313

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (bap teq)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	142

Raw Statistics		Log-transformed Statistics	
Minimum	0.00349	Minimum of Log Data	-5.658
Maximum	0.225	Maximum of Log Data	-1.492
Mean	0.017	Mean of log Data	-4.916
Median	0.00397	SD of log Data	1.076
SD	0.0338		
Coefficient of Variation	1.985		
Skewness	3.741		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.344	Lilliefors Test Statistic	0.349
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0203	95% H-UCL	0.015
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0175
95% Adjusted-CLT UCL (Chen-1995)	0.0208	97.5% Chebyshev (MVUE) UCL	0.0195
95% Modified-t UCL (Johnson-1978)	0.0204	99% Chebyshev (MVUE) UCL	0.0233

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.71	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.024	
MLE of Mean	0.017	
MLE of Standard Deviation	0.0202	
nu star	407.4	
Approximate Chi Square Value (.05)	361.6	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 0.0203
Adjusted Chi Square Value	361.4	95% Jackknife UCL 0.0203
		95% Standard Bootstrap UCL 0.0202
Anderson-Darling Test Statistic	44.09	95% Bootstrap-t UCL 0.021
Anderson-Darling 5% Critical Value	0.8	95% Hall's Bootstrap UCL 0.0208
Kolmogorov-Smirnov Test Statistic	0.367	95% Percentile Bootstrap UCL 0.0203
Kolmogorov-Smirnov 5% Critical Value	0.0559	95% BCA Bootstrap UCL 0.0209
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0257
		97.5% Chebyshev(Mean, Sd) UCL 0.0295
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0369
95% Approximate Gamma UCL	0.0192	
95% Adjusted Gamma UCL	0.0192	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0257

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (barium)

General Statistics

Number of Valid Observations	7	Number of Distinct Observations	7

Raw Statistics		Log-transformed Statistics	
Minimum	52	Minimum of Log Data	3.951
Maximum	103	Maximum of Log Data	4.635
Mean	70.01	Mean of log Data	4.22
Median	61.3	SD of log Data	0.253
SD	19.24		
Coefficient of Variation	0.275		
Skewness	1.215		

Warning: A sample size of 'n' = 7 may not adequate enough to compute meaningful and reliable test statistics and estimates!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Warning: There are only 7 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.781	Shapiro Wilk Test Statistic	0.814
Shapiro Wilk Critical Value	0.803	Shapiro Wilk Critical Value	0.803
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	84.15	95% H-UCL	87.19
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	99.07
95% Adjusted-CLT UCL (Chen-1995)	85.55	97.5% Chebyshev (MVUE) UCL	111.7
95% Modified-t UCL (Johnson-1978)	84.7	99% Chebyshev (MVUE) UCL	136.5

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	10.04	**Data appear Lognormal at 5% Significance Level**	
Theta Star	6.975		
MLE of Mean	70.01		
MLE of Standard Deviation	22.1		
nu star	140.5		
Approximate Chi Square Value (.05)	114.1	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0158	95% CLT UCL	81.98
Adjusted Chi Square Value	106.9	95% Jackknife UCL	84.15
		95% Standard Bootstrap UCL	81.11
Anderson-Darling Test Statistic	0.843	95% Bootstrap-t UCL	126.1
Anderson-Darling 5% Critical Value	0.707	95% Hall's Bootstrap UCL	239.9
Kolmogorov-Smirnov Test Statistic	0.38	95% Percentile Bootstrap UCL	81.99
Kolmogorov-Smirnov 5% Critical Value	0.312	95% BCA Bootstrap UCL	83.77
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	101.7
		97.5% Chebyshev(Mean, Sd) UCL	115.4
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	142.4
95% Approximate Gamma UCL	86.2		
95% Adjusted Gamma UCL	91.99		

Potential UCL to Use	
Use 95% Student's-t UCL	84.15
or 95% Modified-t UCL	84.7
or 95% H-UCL	87.19

ProUCL computes and outputs H-statistic based UCLs for historical reasons only.
H-statistic often results in unstable (both high and low) values of UCL95 as shown in examples in the Technical Guide.
It is therefore recommended to avoid the use of H-statistic based 95% UCLs.
Use of nonparametric methods are preferred to compute UCL95 for skewed data sets which do not follow a gamma distribution.

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzene)

General Statistics

Number of Valid Observations	318	Number of Distinct Observations	253

Raw Statistics		Log-transformed Statistics	
Minimum	0.00182	Minimum of Log Data	-6.309
Maximum	82	Maximum of Log Data	4.407
Mean	1.501	Mean of log Data	-3.895
Median	0.00585	SD of log Data	2.582
SD	6.668		
Coefficient of Variation	4.443		
Skewness	7.589		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.411	Lilliefors Test Statistic	0.286
Lilliefors Critical Value	0.0497	Lilliefors Critical Value	0.0497
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	2.118	95% H-UCL	0.981
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.222
95% Adjusted-CLT UCL (Chen-1995)	2.286	97.5% Chebyshev (MVUE) UCL	1.514
95% Modified-t UCL (Johnson-1978)	2.144	99% Chebyshev (MVUE) UCL	2.089

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.175	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	8.57	
MLE of Mean	1.501	
MLE of Standard Deviation	3.586	
nu star	111.4	
Approximate Chi Square Value (.05)	88.03	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 2.116
Adjusted Chi Square Value	87.93	95% Jackknife UCL 2.118
		95% Standard Bootstrap UCL 2.111
Anderson-Darling Test Statistic	59.16	95% Bootstrap-t UCL 2.402
Anderson-Darling 5% Critical Value	0.987	95% Hall's Bootstrap UCL 2.575
Kolmogorov-Smirnov Test Statistic	0.353	95% Percentile Bootstrap UCL 2.162
Kolmogorov-Smirnov 5% Critical Value	0.0577	95% BCA Bootstrap UCL 2.291
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 3.131
		97.5% Chebyshev(Mean, Sd) UCL 3.836
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 5.221
95% Approximate Gamma UCL	1.899	
95% Adjusted Gamma UCL	1.901	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	3.131

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzo(a)anthracene)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	107

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	0.0988	Maximum of Log Data	-2.315
Mean	0.00777	Mean of log Data	-5.732
Median	0.00173	SD of log Data	1.103
SD	0.0154		
Coefficient of Variation	1.988		
Skewness	3.683		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.343	Lilliefors Test Statistic	0.352
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.00927	95% H-UCL	0.00688
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00805
95% Adjusted-CLT UCL (Chen-1995)	0.00948	97.5% Chebyshev (MVUE) UCL	0.00896
95% Modified-t UCL (Johnson-1978)	0.00931	99% Chebyshev (MVUE) UCL	0.0108

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.688	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0113	
MLE of Mean	0.00777	
MLE of Standard Deviation	0.00937	
nu star	394.7	
Approximate Chi Square Value (.05)	349.6	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 0.00927
Adjusted Chi Square Value	349.4	95% Jackknife UCL 0.00927
		95% Standard Bootstrap UCL 0.00925
Anderson-Darling Test Statistic	43.79	95% Bootstrap-t UCL 0.00961
Anderson-Darling 5% Critical Value	0.802	95% Hall's Bootstrap UCL 0.00945
Kolmogorov-Smirnov Test Statistic	0.371	95% Percentile Bootstrap UCL 0.00927
Kolmogorov-Smirnov 5% Critical Value	0.056	95% BCA Bootstrap UCL 0.00952
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0117
		97.5% Chebyshev(Mean, Sd) UCL 0.0135
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0168
95% Approximate Gamma UCL	0.00877	
95% Adjusted Gamma UCL	0.00878	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0117

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzo(a)pyrene)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	109

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	0.097	Maximum of Log Data	-2.333
Mean	0.00782	Mean of log Data	-5.741
Median	0.00172	SD of log Data	1.1
SD	0.016		
Coefficient of Variation	2.051		
Skewness	3.736		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.347	Lilliefors Test Statistic	0.349
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.00938	95% H-UCL	0.0068
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00794
95% Adjusted-CLT UCL (Chen-1995)	0.0096	97.5% Chebyshev (MVUE) UCL	0.00884
95% Modified-t UCL (Johnson-1978)	0.00941	99% Chebyshev (MVUE) UCL	0.0106

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.677	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0115	
MLE of Mean	0.00782	
MLE of Standard Deviation	0.0095	
nu star	388.6	
Approximate Chi Square Value (.05)	343.9	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 0.00937
Adjusted Chi Square Value	343.7	95% Jackknife UCL 0.00938
		95% Standard Bootstrap UCL 0.00935
Anderson-Darling Test Statistic	44.61	95% Bootstrap-t UCL 0.00965
Anderson-Darling 5% Critical Value	0.804	95% Hall's Bootstrap UCL 0.00964
Kolmogorov-Smirnov Test Statistic	0.368	95% Percentile Bootstrap UCL 0.00951
Kolmogorov-Smirnov 5% Critical Value	0.056	95% BCA Bootstrap UCL 0.00958
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0119
		97.5% Chebyshev(Mean, Sd) UCL 0.0137
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0172
95% Approximate Gamma UCL	0.00883	
95% Adjusted Gamma UCL	0.00884	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0119

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzo(b)fluoranthene)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	114

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	0.454	Maximum of Log Data	-0.79
Mean	0.0106	Mean of log Data	-5.706
Median	0.00173	SD of log Data	1.156
SD	0.0389		
Coefficient of Variation	3.664		
Skewness	9.367		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.407	Lilliefors Test Statistic	0.339
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0144	95% H-UCL	0.00758
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00892
95% Adjusted-CLT UCL (Chen-1995)	0.0158	97.5% Chebyshev (MVUE) UCL	0.00998
95% Modified-t UCL (Johnson-1978)	0.0146	99% Chebyshev (MVUE) UCL	0.0121

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.537	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0198	
MLE of Mean	0.0106	
MLE of Standard Deviation	0.0145	
nu star	308.3	
Approximate Chi Square Value (.05)	268.6	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 0.0144
Adjusted Chi Square Value	268.4	95% Jackknife UCL 0.0144
		95% Standard Bootstrap UCL 0.0144
Anderson-Darling Test Statistic	46.41	95% Bootstrap-t UCL 0.0189
Anderson-Darling 5% Critical Value	0.818	95% Hall's Bootstrap UCL 0.0334
Kolmogorov-Smirnov Test Statistic	0.351	95% Percentile Bootstrap UCL 0.0148
Kolmogorov-Smirnov 5% Critical Value	0.0565	95% BCA Bootstrap UCL 0.0161
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0206
		97.5% Chebyshev(Mean, Sd) UCL 0.025
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0335
95% Approximate Gamma UCL	0.0122	
95% Adjusted Gamma UCL	0.0122	

Potential UCL to Use — Use 95% Chebyshev (Mean, Sd) UCL 0.0206

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzo(g,h,i)perylene)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	121

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	0.186	Maximum of Log Data	-1.682
Mean	0.00918	Mean of log Data	-5.687
Median	0.00173	SD of log Data	1.173
SD	0.02		
Coefficient of Variation	2.176		
Skewness	4.5		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.35	Lilliefors Test Statistic	0.339
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0111	95% H-UCL	0.0079
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00932
95% Adjusted-CLT UCL (Chen-1995)	0.0115	97.5% Chebyshev (MVUE) UCL	0.0104
95% Modified-t UCL (Johnson-1978)	0.0112	99% Chebyshev (MVUE) UCL	0.0127

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.613	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.015	
MLE of Mean	0.00918	
MLE of Standard Deviation	0.0117	
nu star	352	
Approximate Chi Square Value (.05)	309.5	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 0.0111
Adjusted Chi Square Value	309.3	95% Jackknife UCL 0.0111
		95% Standard Bootstrap UCL 0.0111
Anderson-Darling Test Statistic	44.3	95% Bootstrap-t UCL 0.0116
Anderson-Darling 5% Critical Value	0.81	95% Hall's Bootstrap UCL 0.0115
Kolmogorov-Smirnov Test Statistic	0.356	95% Percentile Bootstrap UCL 0.0112
Kolmogorov-Smirnov 5% Critical Value	0.0562	95% BCA Bootstrap UCL 0.0115
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0143
		97.5% Chebyshev(Mean, Sd) UCL 0.0166
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0209
95% Approximate Gamma UCL	0.0104	
95% Adjusted Gamma UCL	0.0105	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0143

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (benzo(k)fluoranthene)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	105

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	0.454	Maximum of Log Data	-0.79
Mean	0.00965	Mean of log Data	-5.757
Median	0.00172	SD of log Data	1.105
SD	0.0381		
Coefficient of Variation	3.944		
Skewness	10.01		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.415	Lilliefors Test Statistic	0.347
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0134	95% H-UCL	0.00673
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00788
95% Adjusted-CLT UCL (Chen-1995)	0.0148	97.5% Chebyshev (MVUE) UCL	0.00878
95% Modified-t UCL (Johnson-1978)	0.0136	99% Chebyshev (MVUE) UCL	0.0105

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.556	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0174	
MLE of Mean	0.00965	
MLE of Standard Deviation	0.0129	
nu star	319.1	
Approximate Chi Square Value (.05)	278.7	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 0.0133
Adjusted Chi Square Value	278.5	95% Jackknife UCL 0.0134
		95% Standard Bootstrap UCL 0.0133
Anderson-Darling Test Statistic	47.7	95% Bootstrap-t UCL 0.0195
Anderson-Darling 5% Critical Value	0.816	95% Hall's Bootstrap UCL 0.0316
Kolmogorov-Smirnov Test Statistic	0.361	95% Percentile Bootstrap UCL 0.0137
Kolmogorov-Smirnov 5% Critical Value	0.0565	95% BCA Bootstrap UCL 0.015
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0194
		97.5% Chebyshev(Mean, Sd) UCL 0.0237
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.032
95% Approximate Gamma UCL	0.011	
95% Adjusted Gamma UCL	0.0111	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0194

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (bis(2-chloroethyl)ether)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.301	
MLE of Mean	0.224	
MLE of Standard Deviation	0.26	
nu star	92.03	
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL 0.366
		95% Standard Bootstrap UCL 0.363
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL 1.158
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.461
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL 0.385
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.457
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.596
		97.5% Chebyshev(Mean, Sd) UCL 0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.075
95% Approximate Gamma UCL	0.29	
95% Adjusted Gamma UCL	0.292	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (bis(2-ethylhexyl)phthalate)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	39

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.27
Median	0.0843	SD of log Data	0.755
SD	0.673		
Coefficient of Variation	3.007		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.432
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.367	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.228
95% Modified-t UCL (Johnson-1978)	0.377	99% Chebyshev (MVUE) UCL	0.282

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.744	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.301	
MLE of Mean	0.224	
MLE of Standard Deviation	0.26	
nu star	92.29	
Approximate Chi Square Value (.05)	71.14	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.365
Adjusted Chi Square Value	70.7	95% Jackknife UCL 0.367
		95% Standard Bootstrap UCL 0.365
Anderson-Darling Test Statistic	19.72	95% Bootstrap-t UCL 1.164
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.474
Kolmogorov-Smirnov Test Statistic	0.514	95% Percentile Bootstrap UCL 0.365
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.44
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.597
		97.5% Chebyshev(Mean, Sd) UCL 0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.075
95% Approximate Gamma UCL	0.291	
95% Adjusted Gamma UCL	0.292	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.597

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (cadmium)

General Statistics

Number of Valid Observations	7	Number of Distinct Observations	7

Raw Statistics		Log-transformed Statistics	
Minimum	0.0224	Minimum of Log Data	-3.801
Maximum	0.469	Maximum of Log Data	-0.757
Mean	0.207	Mean of log Data	-1.903
Median	0.219	SD of log Data	1.007
SD	0.149		
Coefficient of Variation	0.722		
Skewness	0.694		

Warning: A sample size of 'n' = 7 may not adequate enough to compute meaningful and reliable test statistics and estimates!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Warning: There are only 7 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.946	Shapiro Wilk Test Statistic	0.908
Shapiro Wilk Critical Value	0.803	Shapiro Wilk Critical Value	0.803
Data appear Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.316	95% H-UCL	1.14
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.6
95% Adjusted-CLT UCL (Chen-1995)	0.315	97.5% Chebyshev (MVUE) UCL	0.763
95% Modified-t UCL (Johnson-1978)	0.319	99% Chebyshev (MVUE) UCL	1.081

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	1.055	**Data appear Normal at 5% Significance Level**	
Theta Star	0.196		
MLE of Mean	0.207		
MLE of Standard Deviation	0.201		
nu star	14.77		
Approximate Chi Square Value (.05)	7.103	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0158	95% CLT UCL	0.299
Adjusted Chi Square Value	5.577	95% Jackknife UCL	0.316
		95% Standard Bootstrap UCL	0.293
Anderson-Darling Test Statistic	0.265	95% Bootstrap-t UCL	0.341
Anderson-Darling 5% Critical Value	0.719	95% Hall's Bootstrap UCL	0.329
Kolmogorov-Smirnov Test Statistic	0.203	95% Percentile Bootstrap UCL	0.296
Kolmogorov-Smirnov 5% Critical Value	0.316	95% BCA Bootstrap UCL	0.306
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.452
		97.5% Chebyshev(Mean, Sd) UCL	0.559
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.768
95% Approximate Gamma UCL	0.43		
95% Adjusted Gamma UCL	0.547		

Potential UCL to Use		
		Use 95% Student's-t UCL 0.316

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (chlorobenzene)

General Statistics

Number of Valid Observations	63	Number of Distinct Observations	54

Raw Statistics		Log-transformed Statistics	
Minimum	0.00431	Minimum of Log Data	-5.447
Maximum	0.68	Maximum of Log Data	-0.386
Mean	0.0251	Mean of log Data	-4.531
Median	0.0082	SD of log Data	0.878
SD	0.086		
Coefficient of Variation	3.426		
Skewness	7.371		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.432	Lilliefors Test Statistic	0.22
Lilliefors Critical Value	0.112	Lilliefors Critical Value	0.112
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0432	95% H-UCL	0.0201
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0244
95% Adjusted-CLT UCL (Chen-1995)	0.0537	97.5% Chebyshev (MVUE) UCL	0.0282
95% Modified-t UCL (Johnson-1978)	0.0449	99% Chebyshev (MVUE) UCL	0.0355

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.689	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0364	
MLE of Mean	0.0251	
MLE of Standard Deviation	0.0303	
nu star	86.79	
Approximate Chi Square Value (.05)	66.31	**Nonparametric Statistics**
Adjusted Level of Significance	0.0462	95% CLT UCL 0.0429
Adjusted Chi Square Value	65.9	95% Jackknife UCL 0.0432
		95% Standard Bootstrap UCL 0.0427
Anderson-Darling Test Statistic	11.01	95% Bootstrap-t UCL 0.107
Anderson-Darling 5% Critical Value	0.796	95% Hall's Bootstrap UCL 0.101
Kolmogorov-Smirnov Test Statistic	0.37	95% Percentile Bootstrap UCL 0.0462
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.063
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0723
		97.5% Chebyshev(Mean, Sd) UCL 0.0928
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.133
95% Approximate Gamma UCL	0.0329	
95% Adjusted Gamma UCL	0.0331	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0723

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (chromium (total))

General Statistics

Number of Valid Observations	69	Number of Distinct Observations	56

Raw Statistics		**Log-transformed Statistics**	
Minimum	7.69	Minimum of Log Data	2.04
Maximum	50.9	Maximum of Log Data	3.93
Mean	15.84	Mean of log Data	2.686
Median	13.9	SD of log Data	0.378
SD	7.03		
Coefficient of Variation	0.444		
Skewness	2.269		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.159	Lilliefors Test Statistic	0.0736
Lilliefors Critical Value	0.107	Lilliefors Critical Value	0.107
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	17.25	95% H-UCL	17.11
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	18.96
95% Adjusted-CLT UCL (Chen-1995)	17.47	97.5% Chebyshev (MVUE) UCL	20.35
95% Modified-t UCL (Johnson-1978)	17.28	99% Chebyshev (MVUE) UCL	23.09

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	6.47	**Data Follow Appr. Gamma Distribution at 5% Significance Level**
Theta Star	2.447	
MLE of Mean	15.84	
MLE of Standard Deviation	6.225	
nu star	892.9	
Approximate Chi Square Value (.05)	824.5	**Nonparametric Statistics**
Adjusted Level of Significance	0.0465	95% CLT UCL 17.23
Adjusted Chi Square Value	823.1	95% Jackknife UCL 17.25
		95% Standard Bootstrap UCL 17.22
Anderson-Darling Test Statistic	0.81	95% Bootstrap-t UCL 17.53
Anderson-Darling 5% Critical Value	0.753	95% Hall's Bootstrap UCL 17.84
Kolmogorov-Smirnov Test Statistic	0.102	95% Percentile Bootstrap UCL 17.2
Kolmogorov-Smirnov 5% Critical Value	0.107	95% BCA Bootstrap UCL 17.63
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 19.52
		97.5% Chebyshev(Mean, Sd) UCL 21.12
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 24.26
95% Approximate Gamma UCL	17.15	
95% Adjusted Gamma UCL	17.18	

Potential UCL to Use	
Use 95% Approximate Gamma UCL	17.15

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (chrysene)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	134

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	0.783	Maximum of Log Data	-0.245
Mean	0.0179	Mean of log Data	-5.55
Median	0.00175	SD of log Data	1.356
SD	0.0682		
Coefficient of Variation	3.815		
Skewness	8.109		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.405	Lilliefors Test Statistic	0.324
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0245	95% H-UCL	0.0119
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0143
95% Adjusted-CLT UCL (Chen-1995)	0.0266	97.5% Chebyshev (MVUE) UCL	0.0163
95% Modified-t UCL (Johnson-1978)	0.0249	99% Chebyshev (MVUE) UCL	0.0202

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.425	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0421	
MLE of Mean	0.0179	
MLE of Standard Deviation	0.0275	
nu star	243.7	
Approximate Chi Square Value (.05)	208.5	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 0.0245
Adjusted Chi Square Value	208.4	95% Jackknife UCL 0.0245
		95% Standard Bootstrap UCL 0.0245
Anderson-Darling Test Statistic	45.82	95% Bootstrap-t UCL 0.029
Anderson-Darling 5% Critical Value	0.84	95% Hall's Bootstrap UCL 0.0277
Kolmogorov-Smirnov Test Statistic	0.335	95% Percentile Bootstrap UCL 0.0249
Kolmogorov-Smirnov 5% Critical Value	0.0572	95% BCA Bootstrap UCL 0.027
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0354
		97.5% Chebyshev(Mean, Sd) UCL 0.043
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.058
95% Approximate Gamma UCL	0.0209	
95% Adjusted Gamma UCL	0.0209	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0354

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (cis-1,2-dichloroethylene)

General Statistics

Number of Valid Observations	63	Number of Distinct Observations	54

Raw Statistics		Log-transformed Statistics	
Minimum	0.00431	Minimum of Log Data	-5.447
Maximum	0.68	Maximum of Log Data	-0.386
Mean	0.025	Mean of log Data	-4.532
Median	0.0082	SD of log Data	0.877
SD	0.0859		
Coefficient of Variation	3.432		
Skewness	7.388		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.432	Lilliefors Test Statistic	0.22
Lilliefors Critical Value	0.112	Lilliefors Critical Value	0.112
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0431	95% H-UCL	0.0201
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0243
95% Adjusted-CLT UCL (Chen-1995)	0.0536	97.5% Chebyshev (MVUE) UCL	0.0281
95% Modified-t UCL (Johnson-1978)	0.0448	99% Chebyshev (MVUE) UCL	0.0354

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.69	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0363	
MLE of Mean	0.025	
MLE of Standard Deviation	0.0301	
nu star	86.96	
Approximate Chi Square Value (.05)	66.47	**Nonparametric Statistics**
Adjusted Level of Significance	0.0462	95% CLT UCL 0.0429
Adjusted Chi Square Value	66.05	95% Jackknife UCL 0.0431
		95% Standard Bootstrap UCL 0.0429
Anderson-Darling Test Statistic	10.99	95% Bootstrap-t UCL 0.105
Anderson-Darling 5% Critical Value	0.796	95% Hall's Bootstrap UCL 0.101
Kolmogorov-Smirnov Test Statistic	0.37	95% Percentile Bootstrap UCL 0.0456
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.0586
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0722
		97.5% Chebyshev(Mean, Sd) UCL 0.0927
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.133
95% Approximate Gamma UCL	0.0328	
95% Adjusted Gamma UCL	0.033	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0722

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (copper)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	55

Raw Statistics		Log-transformed Statistics	
Minimum	9.69	Minimum of Log Data	2.271
Maximum	52.4	Maximum of Log Data	3.959
Mean	21.15	Mean of log Data	2.974
Median	18.35	SD of log Data	0.388
SD	9.095		
Coefficient of Variation	0.43		
Skewness	1.417		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.164	Lilliefors Test Statistic	0.105
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	23.08	95% H-UCL	23.06
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	25.74
95% Adjusted-CLT UCL (Chen-1995)	23.27	97.5% Chebyshev (MVUE) UCL	27.76
95% Modified-t UCL (Johnson-1978)	23.11	99% Chebyshev (MVUE) UCL	31.73

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	6.258	**Data appear Lognormal at 5% Significance Level**	
Theta Star	3.379		
MLE of Mean	21.15		
MLE of Standard Deviation	8.454		
nu star	776		
Approximate Chi Square Value (.05)	712.4	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0461	95% CLT UCL	23.05
Adjusted Chi Square Value	710.9	95% Jackknife UCL	23.08
		95% Standard Bootstrap UCL	23.05
Anderson-Darling Test Statistic	0.848	95% Bootstrap-t UCL	23.5
Anderson-Darling 5% Critical Value	0.753	95% Hall's Bootstrap UCL	23.32
Kolmogorov-Smirnov Test Statistic	0.129	95% Percentile Bootstrap UCL	22.95
Kolmogorov-Smirnov 5% Critical Value	0.113	95% BCA Bootstrap UCL	23.26
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	26.18
		97.5% Chebyshev(Mean, Sd) UCL	28.36
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	32.64
95% Approximate Gamma UCL	23.04		
95% Adjusted Gamma UCL	23.09		

Potential UCL to Use	
Use 95% Student's-t UCL	23.08
or 95% Modified-t UCL	23.11
or 95% H-UCL	23.06

**ProUCL computes and outputs H-statistic based UCLs for historical reasons only.
H-statistic often results in unstable (both high and low) values of UCL95 as shown in examples in the Technical Guide.
It is therefore recommended to avoid the use of H-statistic based 95% UCLs.
Use of nonparametric methods are preferred to compute UCL95 for skewed data sets which do not follow a gamma distribution.**

**Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.**

Result (1/2 DL for NDs) (cyanide)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	16

Raw Statistics		Log-transformed Statistics	
Minimum	0.029	Minimum of Log Data	-3.54
Maximum	0.15	Maximum of Log Data	-1.897
Mean	0.0398	Mean of log Data	-3.314
Median	0.03	SD of log Data	0.378
SD	0.0228		
Coefficient of Variation	0.572		
Skewness	3.236		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.393	Lilliefors Test Statistic	0.42
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0447	95% H-UCL	0.0426
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0474
95% Adjusted-CLT UCL (Chen-1995)	0.0459	97.5% Chebyshev (MVUE) UCL	0.0511
95% Modified-t UCL (Johnson-1978)	0.0449	99% Chebyshev (MVUE) UCL	0.0582

Gamma Distribution Test		Data Distribution
k star (bias corrected)	5.378	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.00741	
MLE of Mean	0.0398	
MLE of Standard Deviation	0.0172	
nu star	666.8	
Approximate Chi Square Value (.05)	607.9	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.0446
Adjusted Chi Square Value	606.6	95% Jackknife UCL 0.0447
		95% Standard Bootstrap UCL 0.0446
Anderson-Darling Test Statistic	11.02	95% Bootstrap-t UCL 0.0471
Anderson-Darling 5% Critical Value	0.753	95% Hall's Bootstrap UCL 0.0497
Kolmogorov-Smirnov Test Statistic	0.417	95% Percentile Bootstrap UCL 0.0448
Kolmogorov-Smirnov 5% Critical Value	0.113	95% BCA Bootstrap UCL 0.0462
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0524
		97.5% Chebyshev(Mean, Sd) UCL 0.0579
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0686
95% Approximate Gamma UCL	0.0437	
95% Adjusted Gamma UCL	0.0438	

Potential UCL to Use	
Use 95% Student's-t UCL	0.0447
or 95% Modified-t UCL	0.0449

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (cyclohexane)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	57

Raw Statistics		Log-transformed Statistics	
Minimum	0.00505	Minimum of Log Data	-5.288
Maximum	44.9	Maximum of Log Data	3.804
Mean	1.834	Mean of log Data	-3.626
Median	0.0122	SD of log Data	2.332
SD	6.776		
Coefficient of Variation	3.694		
Skewness	4.992		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.472	Lilliefors Test Statistic	0.347
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	3.271	95% H-UCL	1.097
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.061
95% Adjusted-CLT UCL (Chen-1995)	3.833	97.5% Chebyshev (MVUE) UCL	1.369
95% Modified-t UCL (Johnson-1978)	3.362	99% Chebyshev (MVUE) UCL	1.974

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.179	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	10.23	
MLE of Mean	1.834	
MLE of Standard Deviation	4.331	
nu star	22.24	
Approximate Chi Square Value (.05)	12.52	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 3.25
Adjusted Chi Square Value	12.34	95% Jackknife UCL 3.271
		95% Standard Bootstrap UCL 3.234
Anderson-Darling Test Statistic	15.45	95% Bootstrap-t UCL 4.983
Anderson-Darling 5% Critical Value	0.927	95% Hall's Bootstrap UCL 6.997
Kolmogorov-Smirnov Test Statistic	0.446	95% Percentile Bootstrap UCL 3.369
Kolmogorov-Smirnov 5% Critical Value	0.126	95% BCA Bootstrap UCL 3.991
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 5.585
		97.5% Chebyshev(Mean, Sd) UCL 7.208
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 10.4
95% Approximate Gamma UCL	3.258	
95% Adjusted Gamma UCL	3.304	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	5.585

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (dibenzo(a,h)anthracene)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	102

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	0.097	Maximum of Log Data	-2.333
Mean	0.00652	Mean of log Data	-5.801
Median	0.00171	SD of log Data	1.019
SD	0.013		
Coefficient of Variation	1.999		
Skewness	4.326		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.35	Lilliefors Test Statistic	0.355
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0078	95% H-UCL	0.00579
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00669
95% Adjusted-CLT UCL (Chen-1995)	0.008	97.5% Chebyshev (MVUE) UCL	0.0074
95% Modified-t UCL (Johnson-1978)	0.00783	99% Chebyshev (MVUE) UCL	0.00878

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.77	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.00848		
MLE of Mean	0.00652		
MLE of Standard Deviation	0.00744		
nu star	441.7		
Approximate Chi Square Value (.05)	394	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0492	95% CLT UCL	0.00779
Adjusted Chi Square Value	393.8	95% Jackknife UCL	0.0078
		95% Standard Bootstrap UCL	0.00778
Anderson-Darling Test Statistic	44.27	95% Bootstrap-t UCL	0.00809
Anderson-Darling 5% Critical Value	0.796	95% Hall's Bootstrap UCL	0.00808
Kolmogorov-Smirnov Test Statistic	0.376	95% Percentile Bootstrap UCL	0.00788
Kolmogorov-Smirnov 5% Critical Value	0.0557	95% BCA Bootstrap UCL	0.00807
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.00988
		97.5% Chebyshev(Mean, Sd) UCL	0.0113
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0142
95% Approximate Gamma UCL	0.00732		
95% Adjusted Gamma UCL	0.00732		

Potential UCL to Use		
	Use 95% Chebyshev (Mean, Sd) UCL	0.00988

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (dibenzofuran)

General Statistics

Number of Valid Observations	89	Number of Distinct Observations	63

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	17.6	Maximum of Log Data	2.868
Mean	0.447	Mean of log Data	-1.982
Median	0.0895	SD of log Data	0.976
SD	1.932		
Coefficient of Variation	4.32		
Skewness	8.267		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.424	Lilliefors Test Statistic	0.282
Lilliefors Critical Value	0.0939	Lilliefors Critical Value	0.0939
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.787	95% H-UCL	0.28
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.338
95% Adjusted-CLT UCL (Chen-1995)	0.976	97.5% Chebyshev (MVUE) UCL	0.389
95% Modified-t UCL (Johnson-1978)	0.817	99% Chebyshev (MVUE) UCL	0.489

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.523	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.854	
MLE of Mean	0.447	
MLE of Standard Deviation	0.618	
nu star	93.18	
Approximate Chi Square Value (.05)	71.92	**Nonparametric Statistics**
Adjusted Level of Significance	0.0473	95% CLT UCL 0.784
Adjusted Chi Square Value	71.61	95% Jackknife UCL 0.787
		95% Standard Bootstrap UCL 0.777
Anderson-Darling Test Statistic	19.88	95% Bootstrap-t UCL 1.837
Anderson-Darling 5% Critical Value	0.815	95% Hall's Bootstrap UCL 1.792
Kolmogorov-Smirnov Test Statistic	0.393	95% Percentile Bootstrap UCL 0.821
Kolmogorov-Smirnov 5% Critical Value	0.1	95% BCA Bootstrap UCL 1.093
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 1.34
		97.5% Chebyshev(Mean, Sd) UCL 1.726
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 2.484
95% Approximate Gamma UCL	0.579	
95% Adjusted Gamma UCL	0.582	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	1.34

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (dro)

General Statistics

Number of Valid Observations	106	Number of Distinct Observations	95

Raw Statistics		Log-transformed Statistics	
Minimum	5.3	Minimum of Log Data	1.668
Maximum	18800	Maximum of Log Data	9.842
Mean	1061	Mean of log Data	4.416
Median	67.65	SD of log Data	2.503
SD	2482		
Coefficient of Variation	2.34		
Skewness	4.379		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.335	Lilliefors Test Statistic	0.183
Lilliefors Critical Value	0.0861	Lilliefors Critical Value	0.0861
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	1461	95% H-UCL	4965
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	4841
95% Adjusted-CLT UCL (Chen-1995)	1567	97.5% Chebyshev (MVUE) UCL	6203
95% Modified-t UCL (Johnson-1978)	1478	99% Chebyshev (MVUE) UCL	8878

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.273	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	3887	
MLE of Mean	1061	
MLE of Standard Deviation	2030	
nu star	57.85	
Approximate Chi Square Value (.05)	41.36	**Nonparametric Statistics**
Adjusted Level of Significance	0.0477	95% CLT UCL 1457
Adjusted Chi Square Value	41.17	95% Jackknife UCL 1461
		95% Standard Bootstrap UCL 1453
Anderson-Darling Test Statistic	7.258	95% Bootstrap-t UCL 1669
Anderson-Darling 5% Critical Value	0.879	95% Hall's Bootstrap UCL 1914
Kolmogorov-Smirnov Test Statistic	0.193	95% Percentile Bootstrap UCL 1475
Kolmogorov-Smirnov 5% Critical Value	0.0959	95% BCA Bootstrap UCL 1600
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 2111
		97.5% Chebyshev(Mean, Sd) UCL 2566
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 3459
95% Approximate Gamma UCL	1483	
95% Adjusted Gamma UCL	1490	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	2111

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (ethylbenzene)

General Statistics

Number of Valid Observations	318	Number of Distinct Observations	232

Raw Statistics		Log-transformed Statistics	
Minimum	0.00355	Minimum of Log Data	-5.641
Maximum	111	Maximum of Log Data	4.71
Mean	4.876	Mean of log Data	-3.035
Median	0.0113	SD of log Data	2.942
SD	15.47		
Coefficient of Variation	3.173		
Skewness	4.252		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.414	Lilliefors Test Statistic	0.3
Lilliefors Critical Value	0.0497	Lilliefors Critical Value	0.0497
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	6.308	95% H-UCL	7.266
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	8.596
95% Adjusted-CLT UCL (Chen-1995)	6.525	97.5% Chebyshev (MVUE) UCL	10.84
95% Modified-t UCL (Johnson-1978)	6.342	99% Chebyshev (MVUE) UCL	15.26

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.165	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	29.6	
MLE of Mean	4.876	
MLE of Standard Deviation	12.02	
nu star	104.8	
Approximate Chi Square Value (.05)	82.14	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 6.304
Adjusted Chi Square Value	82.05	95% Jackknife UCL 6.308
		95% Standard Bootstrap UCL 6.287
Anderson-Darling Test Statistic	57.15	95% Bootstrap-t UCL 6.554
Anderson-Darling 5% Critical Value	1.016	95% Hall's Bootstrap UCL 6.498
Kolmogorov-Smirnov Test Statistic	0.354	95% Percentile Bootstrap UCL 6.293
Kolmogorov-Smirnov 5% Critical Value	0.0583	95% BCA Bootstrap UCL 6.486
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 8.659
		97.5% Chebyshev(Mean, Sd) UCL 10.3
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 13.51
95% Approximate Gamma UCL	6.219	
95% Adjusted Gamma UCL	6.226	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	8.659

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (fluoranthene)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	125

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	0.387	Maximum of Log Data	-0.949
Mean	0.0135	Mean of log Data	-5.591
Median	0.00174	SD of log Data	1.287
SD	0.0381		
Coefficient of Variation	2.819		
Skewness	5.757		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.376	Lilliefors Test Statistic	0.326
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0172	95% H-UCL	0.0102
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0123
95% Adjusted-CLT UCL (Chen-1995)	0.018	97.5% Chebyshev (MVUE) UCL	0.0139
95% Modified-t UCL (Johnson-1978)	0.0174	99% Chebyshev (MVUE) UCL	0.0171

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.491	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0275	
MLE of Mean	0.0135	
MLE of Standard Deviation	0.0193	
nu star	282.1	
Approximate Chi Square Value (.05)	244.2	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 0.0172
Adjusted Chi Square Value	244	95% Jackknife UCL 0.0172
		95% Standard Bootstrap UCL 0.0173
Anderson-Darling Test Statistic	44.77	95% Bootstrap-t UCL 0.0182
Anderson-Darling 5% Critical Value	0.823	95% Hall's Bootstrap UCL 0.0185
Kolmogorov-Smirnov Test Statistic	0.337	95% Percentile Bootstrap UCL 0.0176
Kolmogorov-Smirnov 5% Critical Value	0.0567	95% BCA Bootstrap UCL 0.0178
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0233
		97.5% Chebyshev(Mean, Sd) UCL 0.0276
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0359
95% Approximate Gamma UCL	0.0156	
95% Adjusted Gamma UCL	0.0156	

Potential UCL to Use — Use 95% Chebyshev (Mean, Sd) UCL 0.0233

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (fluorene)

General Statistics

Number of Valid Observations	314	Number of Distinct Observations	171

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	17.6	Maximum of Log Data	2.868
Mean	0.185	Mean of log Data	-4.592
Median	0.00194	SD of log Data	2.302
SD	1.037		
Coefficient of Variation	5.6		
Skewness	15.31		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.43	Lilliefors Test Statistic	0.277
Lilliefors Critical Value	0.05	Lilliefors Critical Value	0.05
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.282	95% H-UCL	0.224
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.283
95% Adjusted-CLT UCL (Chen-1995)	0.336	97.5% Chebyshev (MVUE) UCL	0.345
95% Modified-t UCL (Johnson-1978)	0.29	99% Chebyshev (MVUE) UCL	0.468

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.245	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.756	
MLE of Mean	0.185	
MLE of Standard Deviation	0.374	
nu star	153.9	
Approximate Chi Square Value (.05)	126.2	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 0.282
Adjusted Chi Square Value	126.1	95% Jackknife UCL 0.282
		95% Standard Bootstrap UCL 0.279
Anderson-Darling Test Statistic	37.99	95% Bootstrap-t UCL 0.469
Anderson-Darling 5% Critical Value	0.896	95% Hall's Bootstrap UCL 0.642
Kolmogorov-Smirnov Test Statistic	0.274	95% Percentile Bootstrap UCL 0.289
Kolmogorov-Smirnov 5% Critical Value	0.0561	95% BCA Bootstrap UCL 0.369
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.44
		97.5% Chebyshev(Mean, Sd) UCL 0.551
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.768
95% Approximate Gamma UCL	0.226	
95% Adjusted Gamma UCL	0.226	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.44

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (gro)

General Statistics

Number of Valid Observations	76	Number of Distinct Observations	69

Raw Statistics		Log-transformed Statistics	
Minimum	0.433	Minimum of Log Data	-0.837
Maximum	7730	Maximum of Log Data	8.953
Mean	289.2	Mean of log Data	1.422
Median	1.275	SD of log Data	2.764
SD	1038		
Coefficient of Variation	3.59		
Skewness	5.727		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.395	Lilliefors Test Statistic	0.312
Lilliefors Critical Value	0.102	Lilliefors Critical Value	0.102
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	487.5	95% H-UCL	782
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	515.9
95% Adjusted-CLT UCL (Chen-1995)	568.6	97.5% Chebyshev (MVUE) UCL	673.1
95% Modified-t UCL (Johnson-1978)	500.5	99% Chebyshev (MVUE) UCL	981.9

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.178	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	1620	
MLE of Mean	289.2	
MLE of Standard Deviation	684.5	
nu star	27.13	
Approximate Chi Square Value (.05)	16.25	**Nonparametric Statistics**
Adjusted Level of Significance	0.0468	95% CLT UCL 485.1
Adjusted Chi Square Value	16.09	95% Jackknife UCL 487.5
		95% Standard Bootstrap UCL 490.5
Anderson-Darling Test Statistic	13.91	95% Bootstrap-t UCL 784.1
Anderson-Darling 5% Critical Value	0.931	95% Hall's Bootstrap UCL 1257
Kolmogorov-Smirnov Test Statistic	0.395	95% Percentile Bootstrap UCL 495.8
Kolmogorov-Smirnov 5% Critical Value	0.114	95% BCA Bootstrap UCL 593
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 808.3
		97.5% Chebyshev(Mean, Sd) UCL 1033
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1474
95% Approximate Gamma UCL	482.7	
95% Adjusted Gamma UCL	487.6	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	808.3

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (hexachloro-1,3-butadiene)

General Statistics

Number of Valid Observations	63	Number of Distinct Observations	38

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.222	Mean of log Data	-2.272
Median	0.084	SD of log Data	0.75
SD	0.668		
Coefficient of Variation	3.011		
Skewness	5.411		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.499	Lilliefors Test Statistic	0.416
Lilliefors Critical Value	0.112	Lilliefors Critical Value	0.112
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.362	95% H-UCL	0.166
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.198
95% Adjusted-CLT UCL (Chen-1995)	0.422	97.5% Chebyshev (MVUE) UCL	0.225
95% Modified-t UCL (Johnson-1978)	0.372	99% Chebyshev (MVUE) UCL	0.278

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.751	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.296	
MLE of Mean	0.222	
MLE of Standard Deviation	0.256	
nu star	94.59	
Approximate Chi Square Value (.05)	73.16	**Nonparametric Statistics**
Adjusted Level of Significance	0.0462	95% CLT UCL 0.36
Adjusted Chi Square Value	72.72	95% Jackknife UCL 0.362
		95% Standard Bootstrap UCL 0.361
Anderson-Darling Test Statistic	19.89	95% Bootstrap-t UCL 1.154
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.439
Kolmogorov-Smirnov Test Statistic	0.498	95% Percentile Bootstrap UCL 0.376
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.447
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.589
		97.5% Chebyshev(Mean, Sd) UCL 0.748
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.06
95% Approximate Gamma UCL	0.287	
95% Adjusted Gamma UCL	0.289	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.589

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (hexachlorobenzene)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281
Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.301		
MLE of Mean	0.224		
MLE of Standard Deviation	0.26		
nu star	92.03		
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0461	95% CLT UCL	0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL	0.366
		95% Standard Bootstrap UCL	0.361
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL	1.161
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL	1.461
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL	0.382
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL	0.449
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.596
		97.5% Chebyshev(Mean, Sd) UCL	0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.075
95% Approximate Gamma UCL	0.29		
95% Adjusted Gamma UCL	0.292		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (hexachlorocyclopentadiene)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	40

Raw Statistics		Log-transformed Statistics	
Minimum	0.201	Minimum of Log Data	-1.604
Maximum	10.9	Maximum of Log Data	2.389
Mean	0.573	Mean of log Data	-1.333
Median	0.216	SD of log Data	0.756
SD	1.726		
Coefficient of Variation	3.011		
Skewness	5.368		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.431
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.939	95% H-UCL	0.428
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.511
95% Adjusted-CLT UCL (Chen-1995)	1.093	97.5% Chebyshev (MVUE) UCL	0.582
95% Modified-t UCL (Johnson-1978)	0.964	99% Chebyshev (MVUE) UCL	0.72

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.772	
MLE of Mean	0.573	
MLE of Standard Deviation	0.665	
nu star	92.06	
Approximate Chi Square Value (.05)	70.93	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.934
Adjusted Chi Square Value	70.49	95% Jackknife UCL 0.939
		95% Standard Bootstrap UCL 0.932
Anderson-Darling Test Statistic	19.75	95% Bootstrap-t UCL 2.977
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 3.748
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL 0.961
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 1.142
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 1.529
		97.5% Chebyshev(Mean, Sd) UCL 1.942
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 2.754
95% Approximate Gamma UCL	0.744	
95% Adjusted Gamma UCL	0.748	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	1.529

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (hexachloroethane)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.301	
MLE of Mean	0.224	
MLE of Standard Deviation	0.26	
nu star	92.03	
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL 0.366
		95% Standard Bootstrap UCL 0.362
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL 1.162
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.459
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL 0.377
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.453
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.596
		97.5% Chebyshev(Mean, Sd) UCL 0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.075
95% Approximate Gamma UCL	0.29	
95% Adjusted Gamma UCL	0.292	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (indeno(1,2,3-c,d)pyrene)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	106

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	0.097	Maximum of Log Data	-2.333
Mean	0.00721	Mean of log Data	-5.764
Median	0.00172	SD of log Data	1.07
SD	0.0142		
Coefficient of Variation	1.967		
Skewness	3.783		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.344	Lilliefors Test Statistic	0.357
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.00859	95% H-UCL	0.0064
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.00745
95% Adjusted-CLT UCL (Chen-1995)	0.00878	97.5% Chebyshev (MVUE) UCL	0.00827
95% Modified-t UCL (Johnson-1978)	0.00862	99% Chebyshev (MVUE) UCL	0.00989

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.719	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.01		
MLE of Mean	0.00721		
MLE of Standard Deviation	0.0085		
nu star	412.5		
Approximate Chi Square Value (.05)	366.4	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0492	95% CLT UCL	0.00858
Adjusted Chi Square Value	366.2	95% Jackknife UCL	0.00859
		95% Standard Bootstrap UCL	0.00856
Anderson-Darling Test Statistic	44.55	95% Bootstrap-t UCL	0.00889
Anderson-Darling 5% Critical Value	0.799	95% Hall's Bootstrap UCL	0.00879
Kolmogorov-Smirnov Test Statistic	0.377	95% Percentile Bootstrap UCL	0.00854
Kolmogorov-Smirnov 5% Critical Value	0.0559	95% BCA Bootstrap UCL	0.00878
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0109
		97.5% Chebyshev(Mean, Sd) UCL	0.0124
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0155
95% Approximate Gamma UCL	0.00811		
95% Adjusted Gamma UCL	0.00812		

Potential UCL to Use			
		Use 95% Chebyshev (Mean, Sd) UCL	0.0109

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (iron)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	54

Raw Statistics		Log-transformed Statistics	
Minimum	7330	Minimum of Log Data	8.9
Maximum	29000	Maximum of Log Data	10.28
Mean	13815	Mean of log Data	9.462
Median	11450	SD of log Data	0.369
SD	5719		
Coefficient of Variation	0.414		
Skewness	1.253		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.176	Lilliefors Test Statistic	0.146
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	15029	95% H-UCL	14974
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	16635
95% Adjusted-CLT UCL (Chen-1995)	15134	97.5% Chebyshev (MVUE) UCL	17885
95% Modified-t UCL (Johnson-1978)	15048	99% Chebyshev (MVUE) UCL	20340

Gamma Distribution Test		Data Distribution
k star (bias corrected)	6.79	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	2035	
MLE of Mean	13815	
MLE of Standard Deviation	5302	
nu star	841.9	
Approximate Chi Square Value (.05)	775.6	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 15010
Adjusted Chi Square Value	774.1	95% Jackknife UCL 15029
		95% Standard Bootstrap UCL 15006
Anderson-Darling Test Statistic	1.956	95% Bootstrap-t UCL 15188
Anderson-Darling 5% Critical Value	0.752	95% Hall's Bootstrap UCL 15168
Kolmogorov-Smirnov Test Statistic	0.161	95% Percentile Bootstrap UCL 14983
Kolmogorov-Smirnov 5% Critical Value	0.113	95% BCA Bootstrap UCL 15176
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 16982
		97.5% Chebyshev(Mean, Sd) UCL 18352
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 21043
95% Approximate Gamma UCL	14997	
95% Adjusted Gamma UCL	15026	

Potential UCL to Use	
Use 95% Student's-t UCL	15029
or 95% Modified-t UCL	15048

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (isophorone)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.301	
MLE of Mean	0.224	
MLE of Standard Deviation	0.26	
nu star	92.03	
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL 0.366
		95% Standard Bootstrap UCL 0.366
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL 1.162
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.46
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL 0.368
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.432
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.596
		97.5% Chebyshev(Mean, Sd) UCL 0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.075
95% Approximate Gamma UCL	0.29	
95% Adjusted Gamma UCL	0.292	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (isopropylbenzene (cumene))

General Statistics

Number of Valid Observations	90	Number of Distinct Observations	80

Raw Statistics		Log-transformed Statistics	
Minimum	0.00431	Minimum of Log Data	-5.447
Maximum	41.6	Maximum of Log Data	3.728
Mean	1.49	Mean of log Data	-3.393
Median	0.011	SD of log Data	2.475
SD	5.375		
Coefficient of Variation	3.607		
Skewness	5.682		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.404	Lilliefors Test Statistic	0.34
Lilliefors Critical Value	0.0934	Lilliefors Critical Value	0.0934
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	2.432	95% H-UCL	2.059
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.864
95% Adjusted-CLT UCL (Chen-1995)	2.785	97.5% Chebyshev (MVUE) UCL	2.397
95% Modified-t UCL (Johnson-1978)	2.489	99% Chebyshev (MVUE) UCL	3.443

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.196	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	7.613	
MLE of Mean	1.49	
MLE of Standard Deviation	3.368	
nu star	35.24	
Approximate Chi Square Value (.05)	22.66	**Nonparametric Statistics**
Adjusted Level of Significance	0.0473	95% CLT UCL 2.422
Adjusted Chi Square Value	22.49	95% Jackknife UCL 2.432
		95% Standard Bootstrap UCL 2.427
Anderson-Darling Test Statistic	17.43	95% Bootstrap-t UCL 3.354
Anderson-Darling 5% Critical Value	0.916	95% Hall's Bootstrap UCL 3.512
Kolmogorov-Smirnov Test Statistic	0.417	95% Percentile Bootstrap UCL 2.459
Kolmogorov-Smirnov 5% Critical Value	0.105	95% BCA Bootstrap UCL 2.976
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 3.96
		97.5% Chebyshev(Mean, Sd) UCL 5.029
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 7.128
95% Approximate Gamma UCL	2.318	
95% Adjusted Gamma UCL	2.335	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	3.96

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (lead)

General Statistics

Number of Valid Observations	7	Number of Distinct Observations	7

Raw Statistics		Log-transformed Statistics	
Minimum	2.79	Minimum of Log Data	1.026
Maximum	7.48	Maximum of Log Data	2.012
Mean	4.257	Mean of log Data	1.404
Median	3.79	SD of log Data	0.308
SD	1.522		
Coefficient of Variation	0.358		
Skewness	1.95		

Warning: A sample size of 'n' = 7 may not adequate enough to compute meaningful and reliable test statistics and estimates!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Warning: There are only 7 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.792	Shapiro Wilk Test Statistic	0.894
Shapiro Wilk Critical Value	0.803	Shapiro Wilk Critical Value	0.803
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	5.375	95% H-UCL	5.65
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	6.398
95% Adjusted-CLT UCL (Chen-1995)	5.657	97.5% Chebyshev (MVUE) UCL	7.332
95% Modified-t UCL (Johnson-1978)	5.446	99% Chebyshev (MVUE) UCL	9.166

Gamma Distribution Test		Data Distribution
k star (bias corrected)	6.575	**Data appear Gamma Distributed at 5% Significance Level**
Theta Star	0.647	
MLE of Mean	4.257	
MLE of Standard Deviation	1.66	
nu star	92.05	
Approximate Chi Square Value (.05)	70.92	**Nonparametric Statistics**
Adjusted Level of Significance	0.0158	95% CLT UCL 5.204
Adjusted Chi Square Value	65.35	95% Jackknife UCL 5.375
		95% Standard Bootstrap UCL 5.131
Anderson-Darling Test Statistic	0.537	95% Bootstrap-t UCL 6.872
Anderson-Darling 5% Critical Value	0.708	95% Hall's Bootstrap UCL 10.21
Kolmogorov-Smirnov Test Statistic	0.247	95% Percentile Bootstrap UCL 5.211
Kolmogorov-Smirnov 5% Critical Value	0.312	95% BCA Bootstrap UCL 5.533
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 6.765
		97.5% Chebyshev(Mean, Sd) UCL 7.851
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 9.983
95% Approximate Gamma UCL	5.525	
95% Adjusted Gamma UCL	5.997	

Potential UCL to Use	
Use 95% Approximate Gamma UCL	5.525

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (m,p-xylene)

General Statistics

Number of Valid Observations	318	Number of Distinct Observations	247

Raw Statistics		Log-transformed Statistics	
Minimum	0.0062	Minimum of Log Data	-5.083
Maximum	499	Maximum of Log Data	6.213
Mean	20.46	Mean of log Data	-2.123
Median	0.0218	SD of log Data	3.239
SD	67.83		
Coefficient of Variation	3.316		
Skewness	4.665		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.419	Lilliefors Test Statistic	0.303
Lilliefors Critical Value	0.0497	Lilliefors Critical Value	0.0497
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	26.73	95% H-UCL	51.81
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	57.21
95% Adjusted-CLT UCL (Chen-1995)	27.78	97.5% Chebyshev (MVUE) UCL	73.07
95% Modified-t UCL (Johnson-1978)	26.9	99% Chebyshev (MVUE) UCL	104.2

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.15	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	136.2	
MLE of Mean	20.46	
MLE of Standard Deviation	52.78	
nu star	95.55	
Approximate Chi Square Value (.05)	74	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 26.71
Adjusted Chi Square Value	73.92	95% Jackknife UCL 26.73
		95% Standard Bootstrap UCL 26.63
Anderson-Darling Test Statistic	54.8	95% Bootstrap-t UCL 28.16
Anderson-Darling 5% Critical Value	1.056	95% Hall's Bootstrap UCL 27.71
Kolmogorov-Smirnov Test Statistic	0.353	95% Percentile Bootstrap UCL 26.65
Kolmogorov-Smirnov 5% Critical Value	0.0591	95% BCA Bootstrap UCL 28.25
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 37.04
		97.5% Chebyshev(Mean, Sd) UCL 44.21
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 58.31
95% Approximate Gamma UCL	26.41	
95% Adjusted Gamma UCL	26.44	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	37.04

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (mercury)

General Statistics

Number of Valid Observations	7	Number of Distinct Observations	7

Raw Statistics		Log-transformed Statistics	
Minimum	0.0175	Minimum of Log Data	-4.048
Maximum	0.0208	Maximum of Log Data	-3.875
Mean	0.0188	Mean of log Data	-3.976
Median	0.0189	SD of log Data	0.0626
SD	0.00119		
Coefficient of Variation	0.0632		
Skewness	0.512		

Warning: A sample size of 'n' = 7 may not adequate enough to compute meaningful and reliable test statistics and estimates!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Warning: There are only 7 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.931	Shapiro Wilk Test Statistic	0.934
Shapiro Wilk Critical Value	0.803	Shapiro Wilk Critical Value	0.803
Data appear Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0197	95% H-UCL	N/A
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0207
95% Adjusted-CLT UCL (Chen-1995)	0.0196	97.5% Chebyshev (MVUE) UCL	0.0216
95% Modified-t UCL (Johnson-1978)	0.0197	99% Chebyshev (MVUE) UCL	0.0232

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	169.4	**Data appear Normal at 5% Significance Level**	
Theta Star	0.000111		
MLE of Mean	0.0188		
MLE of Standard Deviation	0.00144		
nu star	2371		
Approximate Chi Square Value (.05)	2259	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0158	95% CLT UCL	0.0195
Adjusted Chi Square Value	2226	95% Jackknife UCL	0.0197
		95% Standard Bootstrap UCL	0.0195
Anderson-Darling Test Statistic	0.313	95% Bootstrap-t UCL	0.0197
Anderson-Darling 5% Critical Value	0.708	95% Hall's Bootstrap UCL	0.0195
Kolmogorov-Smirnov Test Statistic	0.233	95% Percentile Bootstrap UCL	0.0195
Kolmogorov-Smirnov 5% Critical Value	0.311	95% BCA Bootstrap UCL	0.0195
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.0207
		97.5% Chebyshev(Mean, Sd) UCL	0.0216
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.0233
95% Approximate Gamma UCL	0.0197		
95% Adjusted Gamma UCL	0.02		

Potential UCL to Use	
Use 95% Student's-t UCL	0.0197

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (methyl tert-butyl ether (mtbe))

General Statistics

Number of Valid Observations	63	Number of Distinct Observations	56

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0171	Minimum of Log Data	-4.069
Maximum	2.7	Maximum of Log Data	0.993
Mean	0.0995	Mean of log Data	-3.152
Median	0.0327	SD of log Data	0.876
SD	0.341		
Coefficient of Variation	3.43		
Skewness	7.387		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.431	Lilliefors Test Statistic	0.218
Lilliefors Critical Value	0.112	Lilliefors Critical Value	0.112
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.171	95% H-UCL	0.0799
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0967
95% Adjusted-CLT UCL (Chen-1995)	0.213	97.5% Chebyshev (MVUE) UCL	0.112
95% Modified-t UCL (Johnson-1978)	0.178	99% Chebyshev (MVUE) UCL	0.141
Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.691	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.144		
MLE of Mean	0.0995		
MLE of Standard Deviation	0.12		
nu star	87.02		
Approximate Chi Square Value (.05)	66.51	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0462	95% CLT UCL	0.17
Adjusted Chi Square Value	66.09	95% Jackknife UCL	0.171
		95% Standard Bootstrap UCL	0.168
Anderson-Darling Test Statistic	10.99	95% Bootstrap-t UCL	0.429
Anderson-Darling 5% Critical Value	0.796	95% Hall's Bootstrap UCL	0.399
Kolmogorov-Smirnov Test Statistic	0.369	95% Percentile Bootstrap UCL	0.183
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL	0.258
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.287
		97.5% Chebyshev(Mean, Sd) UCL	0.368
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.527
95% Approximate Gamma UCL	0.13		
95% Adjusted Gamma UCL	0.131		
Potential UCL to Use		Use 95% Chebyshev (Mean, Sd) UCL	0.287

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (methylene chloride)

General Statistics

Number of Valid Observations	63	Number of Distinct Observations	58

Raw Statistics		Log-transformed Statistics	
Minimum	0.0171	Minimum of Log Data	-4.069
Maximum	2.7	Maximum of Log Data	0.993
Mean	0.103	Mean of log Data	-3.093
Median	0.0344	SD of log Data	0.889
SD	0.341		
Coefficient of Variation	3.307		
Skewness	7.364		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.42	Lilliefors Test Statistic	0.229
Lilliefors Critical Value	0.112	Lilliefors Critical Value	0.112
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.175	95% H-UCL	0.086
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.104
95% Adjusted-CLT UCL (Chen-1995)	0.216	97.5% Chebyshev (MVUE) UCL	0.12
95% Modified-t UCL (Johnson-1978)	0.182	99% Chebyshev (MVUE) UCL	0.152

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.707	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.146	
MLE of Mean	0.103	
MLE of Standard Deviation	0.123	
nu star	89.06	
Approximate Chi Square Value (.05)	68.3	**Nonparametric Statistics**
Adjusted Level of Significance	0.0462	95% CLT UCL 0.174
Adjusted Chi Square Value	67.87	95% Jackknife UCL 0.175
		95% Standard Bootstrap UCL 0.171
Anderson-Darling Test Statistic	9.999	95% Bootstrap-t UCL 0.429
Anderson-Darling 5% Critical Value	0.794	95% Hall's Bootstrap UCL 0.41
Kolmogorov-Smirnov Test Statistic	0.367	95% Percentile Bootstrap UCL 0.183
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.237
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.29
		97.5% Chebyshev(Mean, Sd) UCL 0.372
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.531
95% Approximate Gamma UCL	0.134	
95% Adjusted Gamma UCL	0.135	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.29

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (naphthalene)

General Statistics

Number of Valid Observations	314	Number of Distinct Observations	216

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	125	Maximum of Log Data	4.828
Mean	2.129	Mean of log Data	-3.95
Median	0.00705	SD of log Data	3.112
SD	9.112		
Coefficient of Variation	4.28		
Skewness	9.47		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.408	Lilliefors Test Statistic	0.213
Lilliefors Critical Value	0.05	Lilliefors Critical Value	0.05
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	2.978	95% H-UCL	5.274
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	6.002
95% Adjusted-CLT UCL (Chen-1995)	3.269	97.5% Chebyshev (MVUE) UCL	7.631
95% Modified-t UCL (Johnson-1978)	3.023	99% Chebyshev (MVUE) UCL	10.83

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.162	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	13.13	
MLE of Mean	2.129	
MLE of Standard Deviation	5.288	
nu star	101.8	
Approximate Chi Square Value (.05)	79.55	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 2.975
Adjusted Chi Square Value	79.46	95% Jackknife UCL 2.978
		95% Standard Bootstrap UCL 2.944
Anderson-Darling Test Statistic	46.01	95% Bootstrap-t UCL 3.645
Anderson-Darling 5% Critical Value	1.022	95% Hall's Bootstrap UCL 6.344
Kolmogorov-Smirnov Test Statistic	0.313	95% Percentile Bootstrap UCL 3.036
Kolmogorov-Smirnov 5% Critical Value	0.0587	95% BCA Bootstrap UCL 3.382
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 4.371
		97.5% Chebyshev(Mean, Sd) UCL 5.341
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 7.246
95% Approximate Gamma UCL	2.726	
95% Adjusted Gamma UCL	2.729	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	4.371

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (n-butylbenzene)

General Statistics

Number of Valid Observations	90	Number of Distinct Observations	80

Raw Statistics		Log-transformed Statistics	
Minimum	0.00431	Minimum of Log Data	-5.447
Maximum	107	Maximum of Log Data	4.673
Mean	2.166	Mean of log Data	-3.554
Median	0.0105	SD of log Data	2.367
SD	11.88		
Coefficient of Variation	5.485		
Skewness	8.124		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.428	Lilliefors Test Statistic	0.322
Lilliefors Critical Value	0.0934	Lilliefors Critical Value	0.0934
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	4.248	95% H-UCL	1.242
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.193
95% Adjusted-CLT UCL (Chen-1995)	5.373	97.5% Chebyshev (MVUE) UCL	1.527
95% Modified-t UCL (Johnson-1978)	4.427	99% Chebyshev (MVUE) UCL	2.182

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.175	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	12.35	
MLE of Mean	2.166	
MLE of Standard Deviation	5.173	
nu star	31.57	
Approximate Chi Square Value (.05)	19.73	**Nonparametric Statistics**
Adjusted Level of Significance	0.0473	95% CLT UCL 4.227
Adjusted Chi Square Value	19.58	95% Jackknife UCL 4.248
		95% Standard Bootstrap UCL 4.218
Anderson-Darling Test Statistic	19.8	95% Bootstrap-t UCL 14.26
Anderson-Darling 5% Critical Value	0.937	95% Hall's Bootstrap UCL 11.54
Kolmogorov-Smirnov Test Statistic	0.405	95% Percentile Bootstrap UCL 4.481
Kolmogorov-Smirnov 5% Critical Value	0.105	95% BCA Bootstrap UCL 6.297
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 7.626
		97.5% Chebyshev(Mean, Sd) UCL 9.989
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 14.63
95% Approximate Gamma UCL	3.466	
95% Adjusted Gamma UCL	3.493	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	7.626

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (n-hexane)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	58

Raw Statistics		Log-transformed Statistics	
Minimum	0.00505	Minimum of Log Data	-5.288
Maximum	13	Maximum of Log Data	2.565
Mean	0.836	Mean of log Data	-3.786
Median	0.0103	SD of log Data	2.146
SD	2.77		
Coefficient of Variation	3.315		
Skewness	3.741		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.473	Lilliefors Test Statistic	0.334
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	1.423	95% H-UCL	0.553
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.574
95% Adjusted-CLT UCL (Chen-1995)	1.593	97.5% Chebyshev (MVUE) UCL	0.735
95% Modified-t UCL (Johnson-1978)	1.451	99% Chebyshev (MVUE) UCL	1.05

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.204	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	4.088	
MLE of Mean	0.836	
MLE of Standard Deviation	1.848	
nu star	25.35	
Approximate Chi Square Value (.05)	14.88	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 1.414
Adjusted Chi Square Value	14.69	95% Jackknife UCL 1.423
		95% Standard Bootstrap UCL 1.419
Anderson-Darling Test Statistic	14.67	95% Bootstrap-t UCL 1.828
Anderson-Darling 5% Critical Value	0.908	95% Hall's Bootstrap UCL 1.372
Kolmogorov-Smirnov Test Statistic	0.438	95% Percentile Bootstrap UCL 1.477
Kolmogorov-Smirnov 5% Critical Value	0.125	95% BCA Bootstrap UCL 1.713
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 2.369
		97.5% Chebyshev(Mean, Sd) UCL 3.033
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 4.336
95% Approximate Gamma UCL	1.424	
95% Adjusted Gamma UCL	1.442	

Potential UCL to Use		
		Use 95% Chebyshev (Mean, Sd) UCL 2.369

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (nickel)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	52

Raw Statistics		Log-transformed Statistics	
Minimum	8.88	Minimum of Log Data	2.184
Maximum	38	Maximum of Log Data	3.638
Mean	17.58	Mean of log Data	2.807
Median	15.7	SD of log Data	0.341
SD	6.458		
Coefficient of Variation	0.367		
Skewness	1.177		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.133	Lilliefors Test Statistic	0.0788
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	18.95	95% H-UCL	18.96
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	20.92
95% Adjusted-CLT UCL (Chen-1995)	19.06	97.5% Chebyshev (MVUE) UCL	22.39
95% Modified-t UCL (Johnson-1978)	18.97	99% Chebyshev (MVUE) UCL	25.27

Gamma Distribution Test		Data Distribution
k star (bias corrected)	8.181	**Data Follow Appr. Gamma Distribution at 5% Significance Level**
Theta Star	2.149	
MLE of Mean	17.58	
MLE of Standard Deviation	6.145	
nu star	1014	
Approximate Chi Square Value (.05)	941.5	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 18.93
Adjusted Chi Square Value	939.8	95% Jackknife UCL 18.95
		95% Standard Bootstrap UCL 18.93
Anderson-Darling Test Statistic	0.753	95% Bootstrap-t UCL 19.11
Anderson-Darling 5% Critical Value	0.752	95% Hall's Bootstrap UCL 19.06
Kolmogorov-Smirnov Test Statistic	0.0992	95% Percentile Bootstrap UCL 18.92
Kolmogorov-Smirnov 5% Critical Value	0.113	95% BCA Bootstrap UCL 19.13
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 21.15
		97.5% Chebyshev(Mean, Sd) UCL 22.7
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 25.74
95% Approximate Gamma UCL	18.94	
95% Adjusted Gamma UCL	18.97	

Potential UCL to Use	
Use 95% Approximate Gamma UCL	18.94

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (nitrobenzene)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		Log-transformed Statistics	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.301	
MLE of Mean	0.224	
MLE of Standard Deviation	0.26	
nu star	92.03	
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL 0.366
		95% Standard Bootstrap UCL 0.363
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL 1.162
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.461
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL 0.39
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.448
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.596
		97.5% Chebyshev(Mean, Sd) UCL 0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.075
95% Approximate Gamma UCL	0.29	
95% Adjusted Gamma UCL	0.292	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (n-nitrosodimethylamine)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.301	
MLE of Mean	0.224	
MLE of Standard Deviation	0.26	
nu star	92.03	
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**
Adjusted Level of Significance	0.0461	95% CLT UCL 0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL 0.366
		95% Standard Bootstrap UCL 0.363
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL 1.162
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL 1.466
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL 0.377
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL 0.474
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.596
		97.5% Chebyshev(Mean, Sd) UCL 0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1.075
95% Approximate Gamma UCL	0.29	
95% Adjusted Gamma UCL	0.292	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (n-nitroso-di-n-propylamine)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281
Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.301		
MLE of Mean	0.224		
MLE of Standard Deviation	0.26		
nu star	92.03		
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0461	95% CLT UCL	0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL	0.366
		95% Standard Bootstrap UCL	0.368
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL	1.158
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL	1.47
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL	0.392
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL	0.446
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.596
		97.5% Chebyshev(Mean, Sd) UCL	0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.075
95% Approximate Gamma UCL	0.29		
95% Adjusted Gamma UCL	0.292		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (n-nitrosodiphenylamine)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	37

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.0785	Minimum of Log Data	-2.545
Maximum	4.25	Maximum of Log Data	1.447
Mean	0.224	Mean of log Data	-2.274
Median	0.084	SD of log Data	0.756
SD	0.673		
Coefficient of Variation	3.012		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.43
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.366	95% H-UCL	0.167
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.2
95% Adjusted-CLT UCL (Chen-1995)	0.427	97.5% Chebyshev (MVUE) UCL	0.227
95% Modified-t UCL (Johnson-1978)	0.376	99% Chebyshev (MVUE) UCL	0.281

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.301		
MLE of Mean	0.224		
MLE of Standard Deviation	0.26		
nu star	92.03		
Approximate Chi Square Value (.05)	70.91	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0461	95% CLT UCL	0.364
Adjusted Chi Square Value	70.47	95% Jackknife UCL	0.366
		95% Standard Bootstrap UCL	0.364
Anderson-Darling Test Statistic	19.74	95% Bootstrap-t UCL	1.21
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL	1.454
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL	0.37
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL	0.447
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.596
		97.5% Chebyshev(Mean, Sd) UCL	0.758
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.075
95% Approximate Gamma UCL	0.29		
95% Adjusted Gamma UCL	0.292		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.596

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (n-propylbenzene)

General Statistics

Number of Valid Observations	90	Number of Distinct Observations	81

Raw Statistics		Log-transformed Statistics	
Minimum	0.00431	Minimum of Log Data	-5.447
Maximum	72.7	Maximum of Log Data	4.286
Mean	2.69	Mean of log Data	-3.231
Median	0.012	SD of log Data	2.688
SD	9.824		
Coefficient of Variation	3.652		
Skewness	5.432		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.406	Lilliefors Test Statistic	0.358
Lilliefors Critical Value	0.0934	Lilliefors Critical Value	0.0934
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	4.411	95% H-UCL	4.982
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	3.935
95% Adjusted-CLT UCL (Chen-1995)	5.026	97.5% Chebyshev (MVUE) UCL	5.101
95% Modified-t UCL (Johnson-1978)	4.51	99% Chebyshev (MVUE) UCL	7.392

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.179	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	15.02	
MLE of Mean	2.69	
MLE of Standard Deviation	6.356	
nu star	32.24	
Approximate Chi Square Value (.05)	20.26	**Nonparametric Statistics**
Adjusted Level of Significance	0.0473	95% CLT UCL 4.393
Adjusted Chi Square Value	20.1	95% Jackknife UCL 4.411
		95% Standard Bootstrap UCL 4.368
Anderson-Darling Test Statistic	17.54	95% Bootstrap-t UCL 6.389
Anderson-Darling 5% Critical Value	0.934	95% Hall's Bootstrap UCL 10.34
Kolmogorov-Smirnov Test Statistic	0.425	95% Percentile Bootstrap UCL 4.571
Kolmogorov-Smirnov 5% Critical Value	0.105	95% BCA Bootstrap UCL 5.14
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 7.203
		97.5% Chebyshev(Mean, Sd) UCL 9.157
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 12.99
95% Approximate Gamma UCL	4.28	
95% Adjusted Gamma UCL	4.313	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	7.203

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (o-xylene)

General Statistics

Number of Valid Observations	318	Number of Distinct Observations	237

Raw Statistics		Log-transformed Statistics	
Minimum	0.00355	Minimum of Log Data	-5.641
Maximum	211	Maximum of Log Data	5.352
Mean	7.245	Mean of log Data	-2.96
Median	0.0113	SD of log Data	3.06
SD	24.82		
Coefficient of Variation	3.426		
Skewness	5.219		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.417	Lilliefors Test Statistic	0.278
Lilliefors Critical Value	0.0497	Lilliefors Critical Value	0.0497
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	9.542	95% H-UCL	11.76
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	13.57
95% Adjusted-CLT UCL (Chen-1995)	9.97	97.5% Chebyshev (MVUE) UCL	17.21
95% Modified-t UCL (Johnson-1978)	9.61	99% Chebyshev (MVUE) UCL	24.36

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.155	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	46.6	
MLE of Mean	7.245	
MLE of Standard Deviation	18.37	
nu star	98.9	
Approximate Chi Square Value (.05)	76.95	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 9.535
Adjusted Chi Square Value	76.87	95% Jackknife UCL 9.542
		95% Standard Bootstrap UCL 9.449
Anderson-Darling Test Statistic	57.97	95% Bootstrap-t UCL 10.15
Anderson-Darling 5% Critical Value	1.042	95% Hall's Bootstrap UCL 10.12
Kolmogorov-Smirnov Test Statistic	0.359	95% Percentile Bootstrap UCL 9.617
Kolmogorov-Smirnov 5% Critical Value	0.0588	95% BCA Bootstrap UCL 9.984
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 13.31
		97.5% Chebyshev(Mean, Sd) UCL 15.94
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 21.09
95% Approximate Gamma UCL	9.311	
95% Adjusted Gamma UCL	9.322	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	13.31

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (pentachlorophenol)

General Statistics

Number of Valid Observations	62	Number of Distinct Observations	32

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.625	Minimum of Log Data	-0.47
Maximum	33.8	Maximum of Log Data	3.52
Mean	1.778	Mean of log Data	-0.201
Median	0.668	SD of log Data	0.756
SD	5.358		
Coefficient of Variation	3.013		
Skewness	5.366		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.506	Lilliefors Test Statistic	0.431
Lilliefors Critical Value	0.113	Lilliefors Critical Value	0.113
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	2.915	95% H-UCL	1.327
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.586
95% Adjusted-CLT UCL (Chen-1995)	3.393	97.5% Chebyshev (MVUE) UCL	1.804
95% Modified-t UCL (Johnson-1978)	2.992	99% Chebyshev (MVUE) UCL	2.232
Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.742	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	2.397		
MLE of Mean	1.778		
MLE of Standard Deviation	2.064		
nu star	91.99		
Approximate Chi Square Value (.05)	70.87	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0461	95% CLT UCL	2.897
Adjusted Chi Square Value	70.43	95% Jackknife UCL	2.915
		95% Standard Bootstrap UCL	2.89
Anderson-Darling Test Statistic	19.76	95% Bootstrap-t UCL	9.308
Anderson-Darling 5% Critical Value	0.791	95% Hall's Bootstrap UCL	11.63
Kolmogorov-Smirnov Test Statistic	0.513	95% Percentile Bootstrap UCL	3.067
Kolmogorov-Smirnov 5% Critical Value	0.117	95% BCA Bootstrap UCL	3.67
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	4.744
		97.5% Chebyshev(Mean, Sd) UCL	6.027
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	8.548
95% Approximate Gamma UCL	2.308		
95% Adjusted Gamma UCL	2.322		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	4.744

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (phenanthrene)

General Statistics

Number of Valid Observations	314	Number of Distinct Observations	182

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	17.6	Maximum of Log Data	2.868
Mean	0.21	Mean of log Data	-4.593
Median	0.00195	SD of log Data	2.307
SD	1.115		
Coefficient of Variation	5.317		
Skewness	12.89		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.426	Lilliefors Test Statistic	0.273
Lilliefors Critical Value	0.05	Lilliefors Critical Value	0.05
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.313	95% H-UCL	0.227
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.286
95% Adjusted-CLT UCL (Chen-1995)	0.362	97.5% Chebyshev (MVUE) UCL	0.35
95% Modified-t UCL (Johnson-1978)	0.321	99% Chebyshev (MVUE) UCL	0.474

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.236	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.887	
MLE of Mean	0.21	
MLE of Standard Deviation	0.431	
nu star	148.4	
Approximate Chi Square Value (.05)	121.3	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 0.313
Adjusted Chi Square Value	121.2	95% Jackknife UCL 0.313
		95% Standard Bootstrap UCL 0.313
Anderson-Darling Test Statistic	39.31	95% Bootstrap-t UCL 0.45
Anderson-Darling 5% Critical Value	0.9	95% Hall's Bootstrap UCL 0.701
Kolmogorov-Smirnov Test Statistic	0.266	95% Percentile Bootstrap UCL 0.32
Kolmogorov-Smirnov 5% Critical Value	0.0562	95% BCA Bootstrap UCL 0.388
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.484
		97.5% Chebyshev(Mean, Sd) UCL 0.602
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.835
95% Approximate Gamma UCL	0.257	
95% Adjusted Gamma UCL	0.257	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.484

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (pyrene)

General Statistics

Number of Valid Observations	287	Number of Distinct Observations	123

Raw Statistics		Log-transformed Statistics	
Minimum	0.00151	Minimum of Log Data	-6.496
Maximum	0.387	Maximum of Log Data	-0.949
Mean	0.0129	Mean of log Data	-5.61
Median	0.00174	SD of log Data	1.269
SD	0.0369		
Coefficient of Variation	2.864		
Skewness	6.236		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.379	Lilliefors Test Statistic	0.334
Lilliefors Critical Value	0.0523	Lilliefors Critical Value	0.0523
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0165	95% H-UCL	0.0098
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0117
95% Adjusted-CLT UCL (Chen-1995)	0.0173	97.5% Chebyshev (MVUE) UCL	0.0132
95% Modified-t UCL (Johnson-1978)	0.0166	99% Chebyshev (MVUE) UCL	0.0162

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.502	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.0257	
MLE of Mean	0.0129	
MLE of Standard Deviation	0.0182	
nu star	287.9	
Approximate Chi Square Value (.05)	249.6	**Nonparametric Statistics**
Adjusted Level of Significance	0.0492	95% CLT UCL 0.0165
Adjusted Chi Square Value	249.4	95% Jackknife UCL 0.0165
		95% Standard Bootstrap UCL 0.0165
Anderson-Darling Test Statistic	44.81	95% Bootstrap-t UCL 0.0182
Anderson-Darling 5% Critical Value	0.821	95% Hall's Bootstrap UCL 0.0183
Kolmogorov-Smirnov Test Statistic	0.345	95% Percentile Bootstrap UCL 0.0164
Kolmogorov-Smirnov 5% Critical Value	0.0567	95% BCA Bootstrap UCL 0.0177
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.0224
		97.5% Chebyshev(Mean, Sd) UCL 0.0265
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.0345
95% Approximate Gamma UCL	0.0149	
95% Adjusted Gamma UCL	0.0149	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.0224

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (rro)

General Statistics

Number of Valid Observations	121	Number of Distinct Observations	118

Raw Statistics		Log-transformed Statistics	
Minimum	0.0081	Minimum of Log Data	-4.816
Maximum	64700	Maximum of Log Data	11.08
Mean	3710	Mean of log Data	3.628
Median	35.1	SD of log Data	3.949
SD	11419		
Coefficient of Variation	3.078		
Skewness	3.684		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.432	Lilliefors Test Statistic	0.153
Lilliefors Critical Value	0.0805	Lilliefors Critical Value	0.0805
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	5431	95% H-UCL	724592
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	235236
95% Adjusted-CLT UCL (Chen-1995)	5790	97.5% Chebyshev (MVUE) UCL	312717
95% Modified-t UCL (Johnson-1978)	5489	99% Chebyshev (MVUE) UCL	464915

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.166	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	22288	
MLE of Mean	3710	
MLE of Standard Deviation	9094	
nu star	40.29	
Approximate Chi Square Value (.05)	26.74	**Nonparametric Statistics**
Adjusted Level of Significance	0.048	95% CLT UCL 5418
Adjusted Chi Square Value	26.61	95% Jackknife UCL 5431
		95% Standard Bootstrap UCL 5428
Anderson-Darling Test Statistic	8.14	95% Bootstrap-t UCL 6067
Anderson-Darling 5% Critical Value	0.956	95% Hall's Bootstrap UCL 5689
Kolmogorov-Smirnov Test Statistic	0.217	95% Percentile Bootstrap UCL 5487
Kolmogorov-Smirnov 5% Critical Value	0.0945	95% BCA Bootstrap UCL 5722
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 8236
		97.5% Chebyshev(Mean, Sd) UCL 10194
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 14040
95% Approximate Gamma UCL	5589	
95% Adjusted Gamma UCL	5617	

Potential UCL to Use	
Use 99% Chebyshev (Mean, Sd) UCL	14040

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (sec-butylbenzene)

General Statistics

Number of Valid Observations	28	Number of Distinct Observations	28

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.00565	Minimum of Log Data	-5.176
Maximum	25.3	Maximum of Log Data	3.231
Mean	2.228	Mean of log Data	-2.186
Median	0.0189	SD of log Data	2.847
SD	5.249		
Coefficient of Variation	2.356		
Skewness	3.613		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.49	Shapiro Wilk Test Statistic	0.822
Shapiro Wilk Critical Value	0.924	Shapiro Wilk Critical Value	0.924
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	3.917	95% H-UCL	114.8
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	15.51
95% Adjusted-CLT UCL (Chen-1995)	4.583	97.5% Chebyshev (MVUE) UCL	20.6
95% Modified-t UCL (Johnson-1978)	4.03	99% Chebyshev (MVUE) UCL	30.6

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	0.238	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	9.374	
MLE of Mean	2.228	
MLE of Standard Deviation	4.57	
nu star	13.31	
Approximate Chi Square Value (.05)	6.1	**Nonparametric Statistics**
Adjusted Level of Significance	0.0404	95% CLT UCL 3.859
Adjusted Chi Square Value	5.799	95% Jackknife UCL 3.917
		95% Standard Bootstrap UCL 3.819
Anderson-Darling Test Statistic	2.405	95% Bootstrap-t UCL 6.456
Anderson-Darling 5% Critical Value	0.88	95% Hall's Bootstrap UCL 10.26
Kolmogorov-Smirnov Test Statistic	0.311	95% Percentile Bootstrap UCL 3.979
Kolmogorov-Smirnov 5% Critical Value	0.182	95% BCA Bootstrap UCL 4.748
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 6.552
		97.5% Chebyshev(Mean, Sd) UCL 8.423
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 12.1
95% Approximate Gamma UCL	4.86	
95% Adjusted Gamma UCL	5.112	

Potential UCL to Use	
Use 99% Chebyshev (Mean, Sd) UCL	12.1

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (selenium)

General Statistics

Number of Valid Observations	69	Number of Distinct Observations	55

Raw Statistics		Log-transformed Statistics	
Minimum	0.138	Minimum of Log Data	-1.981
Maximum	0.635	Maximum of Log Data	-0.454
Mean	0.254	Mean of log Data	-1.488
Median	0.18	SD of log Data	0.467
SD	0.138		
Coefficient of Variation	0.543		
Skewness	1.31		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.223	Lilliefors Test Statistic	0.215
Lilliefors Critical Value	0.107	Lilliefors Critical Value	0.107
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.282	95% H-UCL	0.28
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.316
95% Adjusted-CLT UCL (Chen-1995)	0.284	97.5% Chebyshev (MVUE) UCL	0.344
95% Modified-t UCL (Johnson-1978)	0.282	99% Chebyshev (MVUE) UCL	0.398

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	4.198	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0606		
MLE of Mean	0.254		
MLE of Standard Deviation	0.124		
nu star	579.3		
Approximate Chi Square Value (.05)	524.5	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0465	95% CLT UCL	0.282
Adjusted Chi Square Value	523.4	95% Jackknife UCL	0.282
		95% Standard Bootstrap UCL	0.281
Anderson-Darling Test Statistic	4.741	95% Bootstrap-t UCL	0.284
Anderson-Darling 5% Critical Value	0.755	95% Hall's Bootstrap UCL	0.282
Kolmogorov-Smirnov Test Statistic	0.219	95% Percentile Bootstrap UCL	0.282
Kolmogorov-Smirnov 5% Critical Value	0.108	95% BCA Bootstrap UCL	0.284
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.327
		97.5% Chebyshev(Mean, Sd) UCL	0.358
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.42
95% Approximate Gamma UCL	0.281		
95% Adjusted Gamma UCL	0.281		

Potential UCL to Use	
Use 95% Student's-t UCL	0.282
or 95% Modified-t UCL	0.282

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (silver)

General Statistics

Number of Valid Observations	7	Number of Distinct Observations	7

Raw Statistics		Log-transformed Statistics	
Minimum	0.0476	Minimum of Log Data	-3.045
Maximum	0.107	Maximum of Log Data	-2.235
Mean	0.0654	Mean of log Data	-2.773
Median	0.0545	SD of log Data	0.316
SD	0.0232		
Coefficient of Variation	0.354		
Skewness	1.355		

Warning: A sample size of 'n' = 7 may not adequate enough to compute meaningful and reliable test statistics and estimates!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Warning: There are only 7 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.765	Shapiro Wilk Test Statistic	0.801
Shapiro Wilk Critical Value	0.803	Shapiro Wilk Critical Value	0.803
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.0825	95% H-UCL	0.0877
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0992
95% Adjusted-CLT UCL (Chen-1995)	0.0846	97.5% Chebyshev (MVUE) UCL	0.114
95% Modified-t UCL (Johnson-1978)	0.0832	99% Chebyshev (MVUE) UCL	0.143

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	6.348	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	0.0103		
MLE of Mean	0.0654		
MLE of Standard Deviation	0.026		
nu star	88.87		
Approximate Chi Square Value (.05)	68.14	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0158	95% CLT UCL	0.0798
Adjusted Chi Square Value	62.68	95% Jackknife UCL	0.0825
		95% Standard Bootstrap UCL	0.0791
Anderson-Darling Test Statistic	0.822	95% Bootstrap-t UCL	0.157
Anderson-Darling 5% Critical Value	0.708	95% Hall's Bootstrap UCL	0.201
Kolmogorov-Smirnov Test Statistic	0.349	95% Percentile Bootstrap UCL	0.0793
Kolmogorov-Smirnov 5% Critical Value	0.312	95% BCA Bootstrap UCL	0.0832
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.104
		97.5% Chebyshev(Mean, Sd) UCL	0.12
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.153
95% Approximate Gamma UCL	0.0853		
95% Adjusted Gamma UCL	0.0928		

Potential UCL to Use	
Use 95% Student's-t UCL	0.0825
or 95% Modified-t UCL	0.0832

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (sulfolane)

General Statistics

Number of Valid Observations	277	Number of Distinct Observations	165

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.00313	Minimum of Log Data	-5.767
Maximum	18.4	Maximum of Log Data	2.912
Mean	0.148	Mean of log Data	-4.618
Median	0.00357	SD of log Data	1.745
SD	1.167		
Std. Error of Mean	0.0701		
Coefficient of Variation	7.881		
Skewness	14.4		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.451	Lilliefors Test Statistic	0.311
Lilliefors Critical Value	0.0532	Lilliefors Critical Value	0.0532
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.264	95% H-UCL	0.061
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.0761
95% Adjusted-CLT UCL (Chen-1995)	0.328	97.5% Chebyshev (MVUE) UCL	0.0898
95% Modified-t UCL (Johnson-1978)	0.274	99% Chebyshev (MVUE) UCL	0.117

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	0.26	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.569	
MLE of Mean	0.148	
MLE of Standard Deviation	0.29	
nu star	144.1	
Approximate Chi Square Value (.05)	117.4	**Nonparametric Statistics**
Adjusted Level of Significance	0.0491	95% CLT UCL 0.263
Adjusted Chi Square Value	117.3	95% Jackknife UCL 0.264
		95% Standard Bootstrap UCL 0.268
Anderson-Darling Test Statistic	52.34	95% Bootstrap-t UCL 0.793
Anderson-Darling 5% Critical Value	0.888	95% Hall's Bootstrap UCL 0.683
Kolmogorov-Smirnov Test Statistic	0.331	95% Percentile Bootstrap UCL 0.278
Kolmogorov-Smirnov 5% Critical Value	0.0599	95% BCA Bootstrap UCL 0.377
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.454
		97.5% Chebyshev(Mean, Sd) UCL 0.586
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.845
95% Approximate Gamma UCL	0.182	
95% Adjusted Gamma UCL	0.182	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.454

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (tert-butylbenzene)

General Statistics

Number of Valid Observations	90	Number of Distinct Observations	80

Raw Statistics		Log-transformed Statistics	
Minimum	0.00431	Minimum of Log Data	-5.447
Maximum	5.4	Maximum of Log Data	1.686
Mean	0.149	Mean of log Data	-4.052
Median	0.0104	SD of log Data	1.497
SD	0.646		
Coefficient of Variation	4.328		
Skewness	6.862		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.411	Lilliefors Test Statistic	0.292
Lilliefors Critical Value	0.0934	Lilliefors Critical Value	0.0934
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	0.262	95% H-UCL	0.0828
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.101
95% Adjusted-CLT UCL (Chen-1995)	0.314	97.5% Chebyshev (MVUE) UCL	0.123
95% Modified-t UCL (Johnson-1978)	0.271	99% Chebyshev (MVUE) UCL	0.164

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.315	**Data do not follow a Discernable Distribution (0.05)**
Theta Star	0.474	
MLE of Mean	0.149	
MLE of Standard Deviation	0.266	
nu star	56.63	
Approximate Chi Square Value (.05)	40.33	**Nonparametric Statistics**
Adjusted Level of Significance	0.0473	95% CLT UCL 0.261
Adjusted Chi Square Value	40.11	95% Jackknife UCL 0.262
		95% Standard Bootstrap UCL 0.262
Anderson-Darling Test Statistic	18.14	95% Bootstrap-t UCL 0.519
Anderson-Darling 5% Critical Value	0.864	95% Hall's Bootstrap UCL 0.64
Kolmogorov-Smirnov Test Statistic	0.399	95% Percentile Bootstrap UCL 0.272
Kolmogorov-Smirnov 5% Critical Value	0.102	95% BCA Bootstrap UCL 0.339
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 0.446
		97.5% Chebyshev(Mean, Sd) UCL 0.574
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 0.827
95% Approximate Gamma UCL	0.21	
95% Adjusted Gamma UCL	0.211	

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	0.446

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (toluene)

General Statistics

Number of Valid Observations	318	Number of Distinct Observations	244

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.00355	Minimum of Log Data	-5.641
Maximum	392	Maximum of Log Data	5.971
Mean	7.684	Mean of log Data	-3.281
Median	0.0117	SD of log Data	2.639
SD	39.51		
Coefficient of Variation	5.142		
Skewness	6.735		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.459	Lilliefors Test Statistic	0.29
Lilliefors Critical Value	0.0497	Lilliefors Critical Value	0.0497
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	11.34	95% H-UCL	2.147
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	2.659
95% Adjusted-CLT UCL (Chen-1995)	12.22	97.5% Chebyshev (MVUE) UCL	3.306
95% Modified-t UCL (Johnson-1978)	11.48	99% Chebyshev (MVUE) UCL	4.576

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.146	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	52.67		
MLE of Mean	7.684		
MLE of Standard Deviation	20.12		
nu star	92.78		
Approximate Chi Square Value (.05)	71.57	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0492	95% CLT UCL	11.33
Adjusted Chi Square Value	71.48	95% Jackknife UCL	11.34
		95% Standard Bootstrap UCL	11.4
Anderson-Darling Test Statistic	71.43	95% Bootstrap-t UCL	12.94
Anderson-Darling 5% Critical Value	1.069	95% Hall's Bootstrap UCL	12
Kolmogorov-Smirnov Test Statistic	0.38	95% Percentile Bootstrap UCL	11.72
Kolmogorov-Smirnov 5% Critical Value	0.0593	95% BCA Bootstrap UCL	12.37
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	17.34
		97.5% Chebyshev(Mean, Sd) UCL	21.52
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	29.73
95% Approximate Gamma UCL	9.961		
95% Adjusted Gamma UCL	9.973		

Potential UCL to Use	
Use 95% Chebyshev (Mean, Sd) UCL	17.34

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (trichlorofluoromethane (freon-11))

General Statistics

Number of Valid Observations	6	Number of Distinct Observations	6

Raw Statistics		Log-transformed Statistics	
Minimum	0.00565	Minimum of Log Data	-5.176
Maximum	22.7	Maximum of Log Data	3.122
Mean	3.874	Mean of log Data	-2.446
Median	0.0636	SD of log Data	3.227
SD	9.224		
Coefficient of Variation	2.381		
Skewness	2.448		

Warning: A sample size of 'n' = 6 may not adequate enough to compute meaningful and reliable test statistics and estimates!

It is suggested to collect at least 8 to 10 observations using these statistical methods!
If possible compute and collect Data Quality Objectives (DQO) based sample size and analytical results.

Warning: There are only 6 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.509	Shapiro Wilk Test Statistic	0.866
Shapiro Wilk Critical Value	0.788	Shapiro Wilk Critical Value	0.788
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	11.46	95% H-UCL	748600000
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	9.143
95% Adjusted-CLT UCL (Chen-1995)	14.09	97.5% Chebyshev (MVUE) UCL	12.3
95% Modified-t UCL (Johnson-1978)	12.09	99% Chebyshev (MVUE) UCL	18.51

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.208	**Data appear Gamma Distributed at 5% Significance Level**	
Theta Star	18.6		
MLE of Mean	3.874		
MLE of Standard Deviation	8.488		
nu star	2.5		
Approximate Chi Square Value (.05)	0.241	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0122	95% CLT UCL	10.07
Adjusted Chi Square Value	0.113	95% Jackknife UCL	11.46
		95% Standard Bootstrap UCL	9.652
Anderson-Darling Test Statistic	0.797	95% Bootstrap-t UCL	656.7
Anderson-Darling 5% Critical Value	0.805	95% Hall's Bootstrap UCL	340.7
Kolmogorov-Smirnov Test Statistic	0.325	95% Percentile Bootstrap UCL	11.35
Kolmogorov-Smirnov 5% Critical Value	0.364	95% BCA Bootstrap UCL	11.49
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	20.29
		97.5% Chebyshev(Mean, Sd) UCL	27.39
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	41.34
95% Approximate Gamma UCL	40.16		
95% Adjusted Gamma UCL	85.76		

Potential UCL to Use		
		Use 95% Adjusted Gamma UCL 85.76

Recommended UCL exceeds the maximum observation

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Result (1/2 DL for NDs) (xylenes (total))

General Statistics

Number of Valid Observations	318	Number of Distinct Observations	259

Raw Statistics		Log-transformed Statistics	
Minimum	0.0104	Minimum of Log Data	-4.566
Maximum	706	Maximum of Log Data	6.56
Mean	25.82	Mean of log Data	-1.785
Median	0.035	SD of log Data	3.132
SD	87.68		
Std. Error of Mean	4.917		
Coefficient of Variation	3.396		
Skewness	4.965		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Lilliefors Test Statistic	0.422	Lilliefors Test Statistic	0.311
Lilliefors Critical Value	0.0497	Lilliefors Critical Value	0.0497
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	33.93	95% H-UCL	49.19
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	55.83
95% Adjusted-CLT UCL (Chen-1995)	35.37	97.5% Chebyshev (MVUE) UCL	71.01
95% Modified-t UCL (Johnson-1978)	34.16	99% Chebyshev (MVUE) UCL	100.8

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.153	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	168.8		
MLE of Mean	25.82		
MLE of Standard Deviation	66.03		
nu star	97.26		
Approximate Chi Square Value (.05)	75.51	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0492	95% CLT UCL	33.91
Adjusted Chi Square Value	75.42	95% Jackknife UCL	33.93
		95% Standard Bootstrap UCL	33.94
Anderson-Darling Test Statistic	56.29	95% Bootstrap-t UCL	36.24
Anderson-Darling 5% Critical Value	1.049	95% Hall's Bootstrap UCL	35.24
Kolmogorov-Smirnov Test Statistic	0.35	95% Percentile Bootstrap UCL	34.18
Kolmogorov-Smirnov 5% Critical Value	0.059	95% BCA Bootstrap UCL	35.27
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	47.25
		97.5% Chebyshev(Mean, Sd) UCL	56.53
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	74.74
95% Approximate Gamma UCL	33.26		
95% Adjusted Gamma UCL	33.3		

Potential UCL to Use		
	Use 95% Chebyshev (Mean, Sd) UCL	47.25

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

ARCADIS

Appendix C

J&E Model Results for Potential Indoor Air Exposures

Input Parameters - 95% UCL

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

DTSC / HERD
Vapor Intrusion Guidance
Interim Final 12/04 last update LA 01/01

YES

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION (enter "X" in "YES" box and initial groundwater conc. below)

YES X

ENTER Chemical CAS No. (numbers only, no dashes)	**ENTER** Initial groundwater conc., C_W (µg/L)	Chemical
95636	113	1,2,4-Trimethylbenzene
108678	121	1,3,5-Trimethylbenzene
91576	35	1-Methylnaphthalene
91576	25.2	2-Methylnaphthalene
71432	1334	Benzene
110827	498	Cyclohexane
100414	180	Ethylbenzene
1634044	3.87	MTBE
91203	145	Naphthalene
110543	64.8	Hexane
103651	80.3	n-Propylbenzene
108883	1427	Toluene
106423	1184	Total Xylenes
		CAS No. not found

Input Parameters - 95% UCL

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
	Depth		Totals must add up to value of L_{WT} (cell G28)					Soil
Average soil/ groundwater temperature, T_S (^oC)	below grade to bottom of enclosed space floor, L_F (cm)	Depth below grade to water table, L_{WT} (cm)	Thickness of soil stratum A, h_A (cm)	Thickness of soil stratum B, (Enter value or 0) h_B (cm)	Thickness of soil stratum C, (Enter value or 0) h_C (cm)	Soil stratum directly above water table, (Enter A, B, or C)	SCS soil type directly above water table	stratum A SCS soil type (used to estimate soil vapor permeability)
5	15	304.0	304.0	0.0		A	SC	S

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Stratum A SCS soil type	Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	Stratum A soil total porosity, n^A (unitless)	Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	Stratum B SCS soil type	Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	Stratum B soil total porosity, n^B (unitless)	Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	Stratum C SCS soil type
Lookup Soil Parameters				Lookup Soil Parameters				Lookup Soil Parameters
S	1.66	0.38	0.054	S	1.66	0.38	0.05	

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Enclosed space floor thickness, L_{crack} (cm)	Soil-bldg. pressure differential, ΔP ($g/cm\text{-}s^2$)	Enclosed space floor length, L_B (cm)	Enclosed space floor width, W_B (cm)	Enclosed space height, H_B (cm)	Floor-wall seam crack width, w (cm)	Indoor air exchange rate, ER (1/h)	Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
10	40	2286	914.4	304.8	0.1	1.0	5

ENTER	ENTER	ENTER	ENTER	ENTER	ENTER
Averaging time for carcinogens, AT_C (yrs)	Averaging time for noncarcinogens, AT_{NC} (yrs)	Exposure duration, ED (yrs)	Exposure frequency, EF (days/yr)	Target risk for carcinogens, TR (unitless)	Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	25	250	1.0E-06	1

Input Parameters - 95% UCL

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)	Stratum B soil air-filled porosity, θ_a^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{te} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{rg} (cm^2)	Stratum A soil effective vapor permeability, k_v (cm^2)	Thickness of capillary zone, L_{cz} (cm)	Total porosity in capillary zone, n_{cz} (cm^3/cm^3)	Air-filled porosity in capillary zone, $\theta_{a,cz}$ (cm^3/cm^3)	Water-filled porosity in capillary zone, $\theta_{w,cz}$ (cm^3/cm^3)	Floor-wall seam perimeter, X_{crack} (cm)
7.9E+08	289	0.321	0.321	--	0.003	9.8E-08	0.998	9.8E-08	30.00	0.375	0.020	0.355	6,401

Bldg. ventilation rate, $Q_{building}$ (cm^3/s)	Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. groundwater temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm^2/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm^2/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm^2/s)	Capillary zone effective diffusion coefficient, D^{eff}_{cz} (cm^2/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)	Diffusion path length, L_d (cm)
1.8E+05	2.2E+06	2.9E-04	15	11,753	1.5E-03	6.5E-02	1.7E-04	9.8E-03	0.0E+00	0.0E+00	2.9E-05	2.7E-04	289
				11,743	1.4E-03	6.2E-02		9.7E-03			3.3E-05	3.1E-04	
				16,306	7.1E-05	3.1E-03		8.4E-03			5.6E-04	3.4E-03	
				16,306	7.1E-05	3.1E-03		8.4E-03			5.6E-04	3.4E-03	
				8,172	2.1E-03	9.0E-02		1.4E-02			2.6E-05	2.5E-04	
				8,273	3.8E-02	1.7E+00		1.2E-02			2.3E-06	2.3E-05	
				10,212	2.3E-03	1.0E-01		1.2E-02			1.9E-05	1.8E-04	
				7,358	2.6E-04	1.1E-02		1.7E-02			2.1E-04	1.9E-03	
				12,964	1.0E-04	4.4E-03		9.5E-03			3.9E-04	2.8E-03	
				7,802	6.4E-01	2.8E+01		3.2E-02			3.3E-06	3.1E-05	
				11,432	2.7E-03	1.2E-01		9.7E-03			1.6E-05	1.5E-04	
				9,208	2.2E-03	9.5E-02		1.4E-02			2.2E-05	2.1E-04	
				10,306	2.2E-03	9.6E-02		1.2E-02			2.1E-05	2.0E-04	

Input Parameters - 95% UCL

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

Convection path length, L_p (cm)	Source vapor conc., C_{source} ($\mu g/m^3$)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, $exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, **α (unitless)**	Infinite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Infinite source bldg. conc., $C_{building}$ (mg/m^3)	Unit risk factor, URF $(\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m^3)	
15	7.3E+03	0.10	8.3E+01	9.8E-03	6.4E+02	5.2E+57	1.1E-05	8.2E-02	8.2E-05	NA	7.0E-03	1,2,4-Trimethylbenzene
	7.5E+03			9.7E-03		1.3E+58	1.3E-05	9.5E-02	9.5E-05	NA	6.0E-03	1,3,5-Trimethylbenzene
	1.1E+02			8.4E-03		9.9E+66	1.1E-04	1.2E-02	1.2E-05	NA	1.4E-02	1-Methylnaphthalene
	7.9E+01			8.4E-03		9.9E+66	1.1E-04	8.8E-03	8.8E-06	NA	1.4E-02	2-Methylnaphthalene
	1.2E+05			1.4E-02		5.6E+39	1.0E-05	1.2E+00	1.2E-03	2.9E-05	3.0E-02	Benzene
	8.2E+05			1.2E-02		3.9E+47	9.6E-07	7.9E-01	7.9E-04	NA	6.0E+00	Cyclohexane
	1.8E+04			1.2E-02		4.3E+46	7.5E-06	1.4E-01	1.4E-04	2.5E-06	1.0E+00	Ethylbenzene
	4.3E+01			1.7E-02		1.4E+34	6.8E-05	2.9E-03	2.9E-06	2.6E-07	3.0E+00	MTBE
	6.3E+02			9.5E-03		1.9E+59	9.4E-05	6.0E-02	6.0E-05	3.4E-05	3.0E-03	Naphthalene
	1.8E+06			3.2E-02		3.1E+17	1.3E-06	2.5E+00	2.5E-03	NA	7.0E-01	Hexane
	9.4E+03			9.7E-03		1.6E+58	6.5E-06	6.0E-02	6.0E-05	NA	1.4E-01	n-Propylbenzene
	1.4E+05			1.4E-02		1.6E+40	8.7E-06	1.2E+00	1.2E-03	NA	3.0E-01	Toluene
	1.1E+05			1.2E-02		3.0E+45	8.4E-06	9.5E-01	9.5E-04	NA	1.0E-01	Total Xylenes

Results - 95% UCL

Human Health Risk Assessment
Flint Hills North Pole Refinery
North Pole, Alaska

RISK-BASED GROUNDWATER CONCENTRATION CALCULATIONS:

INCREMENTAL RISK CALCULATIONS:

Indoor exposure groundwater conc., carcinogen (µg/L)	Indoor exposure groundwater conc., noncarcinogen (µg/L)	Risk-based indoor exposure groundwater conc., (µg/L)	Pure component water solubility, S (µg/L)	Final indoor exposure groundwater conc., (µg/L)	Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)	
NA	NA	NA	5.7E+04	NA	NA	6.7E-03	1,2,4-Trimethylbenzene
NA	NA	NA	2.0E+03	NA	NA	9.1E-03	1,3,5-Trimethylbenzene
NA	NA	NA	2.5E+04	NA	NA	5.0E-04	1-Methylnaphthalene
NA	NA	NA	2.5E+04	NA	NA	3.6E-04	2-Methylnaphthalene
NA	NA	NA	1.8E+06	NA	8.8E-06	2.4E-02	Benzene
NA	NA	NA	5.5E+04	NA	NA	7.5E-05	Cyclohexane
NA	NA	NA	1.7E+05	NA	8.3E-08	7.7E-05	Ethylbenzene
NA	NA	NA	5.1E+07	NA	1.9E-10	5.6E-07	MTBE
NA	NA	NA	3.1E+04	NA	5.0E-07	1.1E-02	Naphthalene
NA	NA	NA	1.2E+04	NA	NA	2.0E-03	Hexane
NA	NA	NA	6.0E+04	NA	NA	2.5E-04	n-Propylbenzene
NA	NA	NA	5.3E+05	NA	NA	2.2E-03	Toluene
NA	NA	NA	1.9E+05	NA	NA	5.5E-03	Total Xylenes

ARCADIS

Appendix D

Estimated Risks/Hazards Using Maximum COPC Concentrations – PPRTV Scenario and ARCADIS Comparative Scenario

Table D-1
Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Indoor Worker Exposed to Indoor Air - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (ug/L) [b]	EPCsg (mg/m^3) [a]	AF [a]	EPCia (mg/m^3) [a]		CANCER RISK: Route-Specific Risk Inhalation (indoor air)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Inhalation (indoor air)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Metals											
Barium	4.8E+02							-			-
Iron	5.7E+04							-			-
Lead	2.1E+00							-			-
VOCs											
1,2,4-Trimethylbenzene	6.1E+02	4.0E+01	1.1E-05	4.5E-04	V	-		-	1.5E-02	1.5E-02	8.0%
1,3,5-Trimethylbenzene	1.8E+02	1.1E+01	1.3E-05	1.4E-04	V	-		-	-		-
4-Isopropyltoluene (p-cymene)	6.0E+01				V			-			-
Benzene	1.9E+04	1.7E+03	1.0E-05	1.7E-02	V	1.1E-05	1.1E-05	93%	1.3E-01	1.3E-01	71.7%
Ethylbenzene	2.8E+03	2.7E+02	7.5E-06	2.1E-03	V	4.2E-07	4.2E-07	4%	4.7E-04	4.7E-04	<1%
n-Propylbenzene	1.2E+02	1.4E+01	6.5E-06	9.2E-05	V	-		-	2.1E-05	2.1E-05	<1%
Toluene	3.0E+04	2.9E+03	8.7E-06	2.5E-02	V	-		-	1.1E-03	1.1E-03	<1%
Xylenes	1.4E+04	1.4E+03	8.4E-06	1.1E-02	V	-		-	2.6E-02	2.6E-02	14.2%
SVOCs											
1-Methylnaphthalene	3.5E+01	1.1E-01	1.1E-04	1.2E-05	V	-		-	-		-
2-Methylnaphthalene	3.1E+01	9.7E-02	1.1E-04	1.1E-05	V	-		-	-		-
PAHs											
Naphthalene	3.0E+02	1.3E+00	9.4E-05	1.2E-04	V	3.4E-07	3.4E-07	3%	9.4E-03	9.4E-03	5.2%
Miscellaneous											
Sulfolane	1.0E+04							-			-
GRO	2.1E+04							-			-
DRO	2.2E+03							-			-
RRO	2.8E+02							-			-
Total Risk or Hazard						1E-05	1E-05		2E-01	2E-01	

Abbreviations:

-:	Not applicable	ug/L:	Microgram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCgw:	Exposure point concentration in groundwater (ug/L)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	SVOCs:	Semi-volatile organic compounds
EPCsg:	Exposure point concentration in soil gas (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
AF:	Attenuation factor (unitless)		

Table D-1
Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Indoor Worker Exposed to Indoor Air - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Notes:

[a] Modeled from groundwater data using Johnson & Ettinger Soil Gas Model (USEPA, 2004). A commercial air exchange rate of 1 per hour was used. Results presented in Appendix C.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CI_ATC	25550
CI_ATnc	9125
CI_ED	25
CI_EF	250
CI_ET	8

Exposure Duration CHRONIC

Equations:

ELCRia (VOCs) = ([EPCsg × AF] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQia (VOCs) = ([EPCsg × AF] × ET × EF × ED) / (24 × ATnc × RfC)

Table D-2
Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.6E+00	1.3E+09	5.8E-09			4.0E-06	5.3E-07	2.0E-09	4.5E-06	97%	2.5E-02	3.3E-03	8.8E-05	2.8E-02	52.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08			-	-	-	-	-	1.3E-05	-	-	1.3E-05	<1%
Iron	1.7E+04	1.3E+09	1.3E-05			-	-	-	-	-	2.4E-02	-	-	2.4E-02	44.2%
Lead							-			-		-			-
Nickel	2.0E+01	1.3E+09	1.5E-08			-	-	3.3E-10	3.3E-10	<1%	9.9E-04	-	3.9E-05	1.0E-03	1.9%
VOCs															
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V	-	-	-	-	-	2.2E-06	-	-	2.2E-06	<1%
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V	-	-	-	-	-	-	-	-	-	-
Benzene	5.1E-02	3.8E+03	1.3E-05		V	9.8E-10	-	8.5E-09	9.5E-09	<1%	1.2E-05	-	1.0E-04	1.1E-04	<1%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V	-	-	-	-	-	-	-	1.0E-06	1.0E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V	8.4E-10	-	7.3E-09	8.1E-09	<1%	2.1E-06	-	8.2E-06	1.0E-05	<1%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V	1.6E-10	-	9.8E-10	1.1E-09	<1%	9.8E-07	-	5.8E-06	6.8E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V	-	-	-	-	-	1.9E-06	-	4.2E-05	4.4E-05	<1%
Toluene	8.2E-02	4.6E+03	1.8E-05		V	-	-	-	-	-	1.0E-06	-	8.1E-07	1.8E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V	-	-	-	-	-	3.6E-06	-	2.7E-04	2.7E-04	<1%
SVOCs															
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V	2.5E-09	-	-	2.5E-09	<1%	3.4E-06	-	-	3.4E-06	<1%
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V	-	-	-	-	-	6.7E-05	-	-	6.7E-05	<1%
PAHs															
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11			*	*	*	*	-	-	-	-	-	-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11			*	*	*	*	-	-	-	-	-	-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11			*	*	*	*	-	-	-	-	-	-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11			*	*	*	*	-	-	-	-	-	-
Chrysene	6.6E-02	1.3E+09	5.0E-11			*	*	*	*	-	-	-	-	-	-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11			*	*	*	*	-	-	-	-	-	-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11			*	*	*	*	-	-	-	-	-	-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V	-	-	3.3E-09	3.3E-09	<1%	2.9E-06	1.7E-06	9.0E-05	9.5E-05	<1%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11			8.1E-08	4.7E-08	2.2E-12	1.3E-07	3%	-	-	-	-	-
Miscellaneous															
Sulfolane	3.8E-02	1.3E+09	2.9E-11			-	-	-	-	-	3.7E-05	-	-	3.7E-05	<1%
GRO	5.4E+00	1.3E+09	4.1E-09			-	-	-	-	-	-	-	-	-	-
DRO	2.1E+02	1.3E+09	1.6E-07			-	-	-	-	-	-	-	-	-	-
RRO	1.9E+03	1.3E+09	1.4E-06			-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard						4E-06	6E-07	2E-08	5E-06		5E-02	3E-03	6E-04	5E-02	
Total Risk or Hazard Excluding Arsenic						9E-08	5E-08	2E-08	2E-07		2E-02	2E-06	6E-04	3E-02	

Table D-2
Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK: Route-Specific Risk: Oral	Dermal	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard: Oral	Dermal	Inhalation (ambient)	Calculated Hazard	Percent Total HI

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

				Exposure Duration	CHRONIC
Clo_ATc	25550		Clo_ET	8	
Clo_ATnc	9125		Clo_EvFs	1	
Clo_AF	0.2		Clo_FI	1	
Clo_BW	70		Clo_IRs	100	
Clo_ED	25		Clo_PEF	1316000000	
Clo_EF	250		Clo_SA	2230	

Equations:

ELCRo = (EPCs × FI × IRs × EF × ED × CSFo) / (1,000,000 × BW × ATc)
ELCRd = ([EPCs × AF × ABSd] × SA × EvFs × EF × ED × CSFd) / (1,000,000 × BW × ATc)
ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCs × FI × IRs × EF × ED) / (1,000,000 × BW × ATnc × RfDo)
HQd = ([EPCs × AF ×ABSd]) × SA ×EvFs × EF × ED) / (1,000,000 × BW × ATnc × RfDa)
HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table D-3a
Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Subsurface Soil (0 to 15 ft below ground surface) - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals														
Arsenic	1.8E+01	1.0E+06	1.8E-05		6.1E-07	3.7E-08	1.5E-08	6.6E-07	69%	5.7E-03	3.5E-04	1.7E-02	2.3E-02	8.1%
Chromium, Total	5.1E+01	1.0E+06	5.1E-05		-	-	-	-	-	5.5E-05	-	-	5.5E-05	<1%
Iron	2.9E+04	1.0E+06	2.9E-02		-	-	-	-	-	6.7E-02	-	-	6.7E-02	23.8%
Nickel	3.8E+01	1.0E+06	3.8E-05		-	-	2.0E-09	2.0E-09	<1%	3.1E-03	-	6.0E-03	9.1E-03	3.2%
VOCs														
1,2,4-Trimethylbenzene	2.1E+02	8.5E+03	2.4E-02	V	-	-	-	-	-	-	-	4.9E-03	4.9E-03	1.7%
1,3,5-Trimethylbenzene	8.1E+01	7.1E+03	1.1E-02	V	-	-	-	-	-	1.3E-03	-	1.6E-02	1.8E-02	6.2%
4-Isopropyltoluene (p-cymene)	2.0E+01	9.4E+03	2.2E-03	V	-	-	-	-	-	-	-	-	-	-
Benzene	8.2E+01	3.8E+03	2.2E-02	V	1.0E-07	-	3.4E-08	1.4E-07	14%	1.3E-02	-	3.8E-03	1.7E-02	6.1%
Cyclohexane	4.5E+01	1.1E+03	4.0E-02	V	-	-	-	-	-	-	-	9.5E-05	9.5E-05	<1%
Ethylbenzene	1.1E+02	6.1E+03	1.8E-02	V	2.8E-08	-	9.3E-09	3.7E-08	4%	3.6E-03	-	2.9E-05	3.6E-03	1.3%
Isopropylbenzene (cumene)	4.2E+01	6.7E+03	6.2E-03	V	-	-	-	-	-	1.7E-04	-	9.9E-04	1.2E-03	<1%
Methylene chloride	1.9E-01	2.4E+03	8.0E-05	V	3.3E-11	-	7.6E-12	4.0E-11	<1%	5.1E-06	-	3.8E-07	5.4E-06	<1%
n-Butylbenzene	1.1E+02	8.8E+03	1.2E-02	V	-	-	-	-	-	1.7E-03	-	-	1.7E-03	<1%
n-Hexane	1.3E+01	8.9E+02	1.5E-02	V	-	-	-	-	-	7.0E-05	-	1.0E-04	1.7E-04	<1%
n-Propylbenzene	7.3E+01	7.5E+03	9.7E-03	V	-	-	-	-	-	1.2E-03	2.4E-04	1.4E-04	1.5E-03	<1%
sec-Butylbenzene	2.5E+01	8.1E+03	3.1E-03	V	-	-	-	-	-	-	-	-	-	-
Toluene	3.9E+02	4.6E+03	8.5E-02	V	-	-	-	-	-	7.9E-04	-	2.4E-04	1.0E-03	<1%
Xylenes	7.1E+02	6.3E+03	1.1E-01	V	-	-	-	-	-	2.8E-03	-	4.0E-03	6.9E-03	2.4%
SVOCs														
1-Methylnaphthalene	8.9E+01	6.3E+04	1.4E-03	V	5.9E-08	-	-	5.9E-08	6%	2.0E-03	-	-	2.0E-03	<1%
2-Methylnaphthalene	2.4E+02	6.2E+04	3.8E-03	V	-	-	-	-	-	9.7E-02	-	-	9.7E-02	34.5%
PAHs														
Benzo (a) anthracene	9.9E-02	1.0E+06	9.9E-08		*	*	*	*	-	-	-	-	-	-
Benzo (a) pyrene	9.5E-02	1.0E+06	9.5E-08		*	*	*	*	-	-	-	-	-	-
Benzo (b) fluoranthene	1.1E-01	1.0E+06	1.1E-07		*	*	*	*	-	-	-	-	-	-
Benzo (k) fluoranthene	4.0E-02	1.0E+06	4.0E-08		*	*	*	*	-	-	-	-	-	-
Chrysene	7.8E-01	1.0E+06	7.8E-07		*	*	*	*	-	-	-	-	-	-
Dibenzo (a,h) anthracene	1.8E-02	1.0E+06	1.8E-08		*	*	*	*	-	-	-	-	-	-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.0E+06	6.9E-08		*	*	*	*	-	-	-	-	-	-
Naphthalene	1.3E+02	5.0E+04	2.5E-03	V	-	-	1.7E-08	1.7E-08	2%	1.0E-02	2.7E-03	1.2E-02	2.5E-02	8.8%
Total Benzo(a)pyrene TEQ	2.3E-01	1.0E+06	2.3E-07		3.8E-08	1.0E-08	5.0E-11	4.8E-08	5%	-	-	-	-	-
Miscellaneous														
Sulfolane	1.8E+01	1.0E+06	1.8E-05		-	-	-	-	-	3.0E-03	-	-	3.0E-03	1.1%
GRO	7.7E+03	1.0E+06	7.7E-03		-	-	-	-	-	-	-	-	-	-
DRO	1.9E+04	1.0E+06	1.9E-02		-	-	-	-	-	-	-	-	-	-
RRO	6.5E+04	1.0E+06	6.5E-02		-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard					8E-07	5E-08	8E-08	1E-06		2E-01	3E-03	7E-02	3E-01	
Total Risk or Hazard Excluding Arsenic					2E-07	1E-08	6E-08	3E-07		2E-01	3E-03	5E-02	3E-01	

Table D-3a
Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Subsurface Soil (0 to 15 ft below ground surface) - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK: Route-Specific Risk: Oral	CANCER RISK: Route-Specific Risk: Dermal	CANCER RISK: Route-Specific Risk: Inhalation (ambient)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard: Oral	NON-CANCER HAZARD: Route-Specific Hazard: Dermal	NON-CANCER HAZARD: Route-Specific Hazard: Inhalation (ambient)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI

Abbreviations:

-:	Not applicable	$mg/m^{3:}$	Milligram(s) per cubic meter
ELCR:	Excess lifetime cancer risk (unitless)	PAH:	Polycyclic aromatic hydrocarbon
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
mg/kg:	Milligram(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk
m^3/kg:	Cubic meter(s) per kilogram		

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CST_ATc	25550	CST_ET	1
CST_ATnc	365	CST_EvFs	1
CST_AF	0.3	CST_FI	1
CST_BW	70	CST_IRs	330
CST_ED	1	CST_PEF	1.00E+06
CST_EF	125	CST_SA	2230

Exposure Duration: SUBCHRONIC

Equations:

$ELCRo = (EPCs \times FI \times IRs \times EF \times ED \times CSFo) / (1{,}000{,}000 \times BW \times ATc)$

$ELCRd = ([EPCs \times AF \times ABSd] \times SA \times EvFs \times EF \times ED \times CSFd) / (1{,}000{,}000 \times BW \times ATc)$

$ELCRaa = ([EPCs / (VF \text{ or } PEF)] \times EF \times ED \times ET \times IUR \times 1000) / (24 \times ATc)$

$HQo = (EPCs \times FI \times IRs \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfDo)$

$HQd = ([EPCs \times AF \times ABSd]) \times SA \times EvFs \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfDa)$

$HQaa = ([EPCs / (VF \text{ or } PEF)] \times ET \times EF \times ED) / (24 \times ATnc \times RfC)$

Table D-3b
Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Groundwater in a Trench - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] (L/cm2/event	EPCta [a] (mg/m3)		CANCER RISK: Route-Specific Risk Oral	CANCER RISK: Route-Specific Risk Dermal	CANCER RISK: Route-Specific Risk Inhalation (trench air)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	NON-CANCER HAZARD: Route-Specific Hazard Dermal	NON-CANCER HAZARD: Route-Specific Hazard Inhalation (trench air)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Metals															
Barium	4.8E-01		1.0E-06			-	-	-	-	-	1.2E-04	1.1E-03		1.2E-03	<1%
Iron	5.7E+01		1.0E-06			-	-	-	-	-	1.5E-03	8.9E-04	-	2.4E-03	<1%
Lead	2.1E-03		1.0E-07			-	-	-	-	-	-	-	-	-	-
VOCs															
1,2,4-Trimethylbenzene	6.1E-01	7.5E+00	2.6E-04	4.6E+00	V	-	-	-	-	-	-	-	9.4E-01	9.4E-01	1.9%
1,3,5-Trimethylbenzene	1.8E-01	7.6E+00	1.8E-04	1.4E+00	V	-	-	-	-	-	3.3E-05	3.7E-03	2.0E+00	2.0E+00	4.1%
4-Isopropyltoluene (p-cymene)	6.0E-02	7.2E+00	5.0E-04	4.3E-01	V	-	-	-	-	-	-	-	-	-	-
Benzene	1.9E+01	9.3E+00	2.3E-05	1.7E+02	V	2.6E-07	3.7E-06	2.7E-04	2.8E-04	92%	3.3E-02	4.7E-01	3.1E+01	3.1E+01	64.4%
Ethylbenzene	2.8E+00	8.0E+00	8.8E-05	2.2E+01	V	7.8E-09	4.1E-07	1.1E-05	1.2E-05	4%	1.0E-03	5.3E-02	3.5E-02	8.9E-02	<1%
n-Propylbenzene	1.2E-01	7.6E+00	2.8E-04	9.2E-01	V	-	-	-	-	-	2.2E-05	3.8E-03	1.3E-02	1.7E-02	<1%
Toluene	3.0E+01	8.6E+00	5.2E-05	2.6E+02	V	-	-	-	-	-	6.8E-04	2.1E-02	7.4E-01	7.6E-01	1.6%
Xylenes	1.4E+01	8.0E+00	9.5E-05	1.1E+02	V	-	-	-	-	-	6.4E-04	3.6E-02	4.0E+00	4.1E+00	8.3%
SVOCs															
1-Methylnaphthalene	3.5E-02	6.3E+00	3.3E-04	2.2E-01	V	2.6E-10	5.2E-08	-	5.2E-08	<1%	9.1E-06	1.8E-03	-	1.8E-03	<1%
2-Methylnaphthalene	3.1E-02	6.3E+00	3.2E-04	2.0E-01	V	-	-	-	-	-	1.4E-04	2.7E-02	-	2.7E-02	<1%
PAHs															
Naphthalene	3.0E-01	6.6E+00	9.7E-05	2.0E+00	V	-	-	1.4E-05	1.4E-05	5%	2.7E-04	1.6E-02	9.4E+00	9.4E+00	19.4%
Miscellaneous															
Sulfolane	1.0E+01		2.0E-07			-	-	-	-	-	1.9E-02	2.3E-03	-	2.1E-02	<1%
GRO	2.1E+01		NA			-	-	-	-	-	-	-	-	-	-
DRO	2.2E+00		NA			-	-	-	-	-	-	-	-	-	-
RRO	2.8E-01		NA			-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard						3E-07	4E-06	3E-04	3E-04		6E-02	6E-01	4.8E+01	4.9E+01	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	mg/m$^{3:}$	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m³:	Liter(s) per cubic meter		

Table D-3b

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Groundwater in a Trench - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Notes:

[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

Parameters (see Table 3-12a for definitions):

Exposure Duration SUBCHRONIC

CST_ATc	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_Flgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Equations:

ELCRo = (EPCgw × Flgw × IRinc_gw × EFgw × ED × CSFo) / (BW × ATc)

ELCRd = (EPCgw × DA × SAgw × EvFgw × EFgw × ED × CSFd) / (BW × ATc)

ELCRta (VOCs) = ([EPCgw × VF] × EFgw × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCgw × Flgw × IRinc_gw × EFgw × ED) / (BW × ATnc × RfDo)

HQd = (EPCgw × DA ×SAgw ×EvFgw × EFgw × ED) / (BW × ATnc × RfDa)

HQta (VOCs) = ([EPCgw × VF] × ET × EFgw × ED) / (24 × ATnc × RfC)

Table D-4
Chronic Risk and Hazard Estimates for the Onsite Adult Visitor Exposed to Indoor Air - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (ug/L) [b]	EPCsg (mg/m^3) [a]	AF [a]	EPCia (mg/m^3) [a]		CANCER RISK: Route-Specific Risk Inhalation (indoor air)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Inhalation (indoor air)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Metals											
Barium	4.8E+02							-			-
Iron	5.7E+04							-			-
Lead	2.1E+00							-			-
VOCs											
1,2,4-Trimethylbenzene	6.1E+02	4.0E+01	1.1E-05	4.5E-04	V	-		-	1.7E-04	1.7E-04	8.0%
1,3,5-Trimethylbenzene	1.8E+02	1.1E+01	1.3E-05	1.4E-04	V	-		-	-		-
4-Isopropyltoluene (p-cymene)	6.0E+01				V			-			-
Benzene	1.9E+04	1.7E+03	1.0E-05	1.7E-02	V	1.6E-07	1.6E-07	93%	1.6E-03	1.6E-03	71.7%
Ethylbenzene	2.8E+03	2.7E+02	7.5E-06	2.1E-03	V	6.1E-09	6.1E-09	4%	5.7E-06	5.7E-06	<1%
n-Propylbenzene	1.2E+02	1.4E+01	6.5E-06	9.2E-05	V	-		-	2.5E-07	2.5E-07	<1%
Toluene	3.0E+04	2.9E+03	8.7E-06	2.5E-02	V	-		-	1.4E-05	1.4E-05	<1%
Xylenes	1.4E+04	1.4E+03	8.4E-06	1.1E-02	V	-		-	3.1E-04	3.1E-04	14.2%
SVOCs											
1-Methylnaphthalene	3.5E+01	1.1E-01	1.1E-04	1.2E-05	V	-		-	-		-
2-Methylnaphthalene	3.1E+01	9.7E-02	1.1E-04	1.1E-05	V	-		-	-		-
PAHs											
Naphthalene	3.0E+02	1.3E+00	9.4E-05	1.2E-04	V	5.0E-09	5.0E-09	3%	1.1E-04	1.1E-04	5.2%
Miscellaneous											
Sulfolane	1.0E+04							-			-
GRO	2.1E+04							-			-
DRO	2.2E+03							-			-
RRO	2.8E+02							-			-
Total Risk or Hazard						2E-07	2E-07		2E-03	2E-03	

Abbreviations:

-:	Not applicable	ug/L:	Microgram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCgw:	Exposure point concentration in groundwater (ug/L)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	SVOCs:	Semi-volatile organic compounds
EPCsg:	Exposure point concentration in soil gas (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
AF:	Attenuation factor (unitless)		

Table D-4
Chronic Risk and Hazard Estimates for the Onsite Adult Visitor Exposed to Indoor Air - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Notes:

[a] Modeled from groundwater data using Johnson & Ettinger Soil Gas Model (USEPA, 2004). A commercial air exchange rate of 1 per hour was used. Results presented in Appendix C.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

VIS_ATC	25550
VIS_ATnc	10950
VIS_ED	30
VIS_EF	12
VIS_ET	2

Exposure Duration CHRONIC

Equations:

ELCRia (VOCs) = ([EPCsg × AF] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQia (VOCs) = ([EPCsg × AF] × ET × EF × ED) / (24 × ATnc × RfC)

Table D-5a
Chronic Risk and Hazard Estimates for the Offsite Adult Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals														
Arsenic	7.6E+00	1.3E+09	5.8E-09				3.9E-09	3.9E-09	9%			1.4E-04	1.4E-04	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08				-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05				-		-			-		-
Lead									-					-
Nickel	2.0E+01	1.3E+09	1.5E-08				6.3E-10	6.3E-10	1%			6.3E-05	6.3E-05	6.0%
VOCs														
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06	V			-		-			-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06	V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05	V			1.6E-08	1.6E-08	38%			1.6E-04	1.6E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05	V			-		-			1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05	V			1.4E-08	1.4E-08	33%			1.3E-05	1.3E-05	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05	V			1.9E-09	1.9E-09	4%			9.5E-06	9.5E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04	V			-		-			6.9E-05	6.9E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05	V			-		-			1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04	V			-		-			4.4E-04	4.4E-04	41.7%
SVOCs														
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06	V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06	V			-		-			-		-
PAHs														
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11				*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11				*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11				*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11				*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11				*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11				*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11				*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06	V			6.4E-09	6.4E-09	15%			1.5E-04	1.5E-04	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11				4.2E-12	4.2E-12	<1%			-		-
Miscellaneous														
Sulfolane	3.8E-02	1.3E+09	2.9E-11				-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09				-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07				-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06				-		-			-		-
Total Risk or Hazard					0E+00	0E+00	4E-08	4E-08		0E+00	0E+00	1E-03	1E-03	
Total Risk or Hazard Excluding Arsenic					0E+00	0E+00	4E-08	4E-08		0E+00	0E+00	9E-04	9E-04	

Table D-5a

Chronic Risk and Hazard Estimates for the Offsite Adult Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

			Exposure Duration	CHRONIC
ADUR_ATc	25550	ADUR_ET	12	
ADUR_ATnc	10950	ADUR_FI	–	
ADUR_AF	–	ADUR_IRs	–	
ADUR_BW	70	ADUR_PEF	1316000000	
ADUR_ED	30	ADUR_SA	–	
ADUR_EF	270			

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table D-5b
Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - All Offsite Wells - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	4.4E-01					-			-	-	1.2E+01			1.2E+01	100.0%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		1.2E+01	0E+00	0E+00	1.2E+01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-5c
Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - All Offsite Wells - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK: Route-Specific Risk Ingestion (fruit)	CANCER RISK: Route-Specific Risk Ingestion (vegetables)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	4.4E-01	1.0E+00	4.4E-01	-	-		-	3.0E-01	4.8E-01	7.9E-01	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		3.0E-01	4.8E-01	7.9E-01	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

		Exposure Duration	CHRONIC
ADUR_ATC	25550	ADUR_IRPfr	259000
ADUR_ATnc	10950	ADUR_IRPvg	413000
ADUR_ED	30	ADUR_FIp	0.25
ADUR_EF	270		
ADUR_BW	70		

Equations:

$ELCRp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED \times CSF) / (1{,}000{,}000 \times BW \times ATC)$

$HIp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfD)$

Table D-6a
Chronic Risk and Hazard Estimates for the Offsite Child Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK: Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals														
Arsenic	7.6E+00	1.3E+09	5.8E-09				7.9E-10	7.9E-10	9%			1.4E-04	1.4E-04	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08				-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05				-		-			-		-
Lead									-					-
Nickel	2.0E+01	1.3E+09	1.5E-08				1.3E-10	1.3E-10	1%			6.3E-05	6.3E-05	6.0%
VOCs														
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06	V			-		-			-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06	V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05	V			3.3E-09	3.3E-09	38%			1.6E-04	1.6E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05	V			-		-			1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05	V			2.8E-09	2.8E-09	33%			1.3E-05	1.3E-05	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05	V			3.8E-10	3.8E-10	4%			9.5E-06	9.5E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04	V			-		-			6.9E-05	6.9E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05	V			-		-			1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04	V			-		-			4.4E-04	4.4E-04	41.7%
SVOCs														
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06	V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06	V			-		-			-		-
PAHs														
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11				*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11				*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11				*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11				*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11				*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11				*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11				*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06	V			1.3E-09	1.3E-09	15%			1.5E-04	1.5E-04	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11				8.4E-13	8.4E-13	<1%			-		-
Miscellaneous														
Sulfolane	3.8E-02	1.3E+09	2.9E-11				-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09				-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07				-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06				-		-			-		-
Total Risk or Hazard					0E+00	0E+00	9E-09	9E-09		0E+00	0E+00	1E-03	1E-03	
Total Risk or Hazard Excluding Arsenic					0E+00	0E+00	8E-09	8E-09		0E+00	0E+00	9E-04	9E-04	

Table D-6a

Chronic Risk and Hazard Estimates for the Offsite Child Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	mg/m$^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m³/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

		Exposure Duration	CHRONIC
CHR_ATc	25550	CHR_ET	12
CHR_ATnc	2190	CHR_FI	–
CHR_AF	–	CHR_IRs	–
CHR_BW	15	CHR_PEF	1316000000
CHR_ED	6	CHR_SA	–
CHR_EF	270		

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table D-6b
Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - All Offsite Wells - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	4.4E-01					-			-	-	2.8E+01			2.8E+01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2.8E+01	0E+00	0E+00	2.8E+01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-6c
Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - All Offsite Wells - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK: Route-Specific Risk Ingestion (fruit)	CANCER RISK: Route-Specific Risk Ingestion (vegetables)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	4.4E-01	1.0E+00	4.4E-01	-	-		-	1.2E+00	1.1E+00	2.3E+00	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		1E+00	1E+00	2E+00	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_IRPfr	223500
CHR_ATnc	2190	CHR_IRPvg	201000
CHR_ED	6	CHR_FIp	0.25
CHR_EF	270		
CHR_BW	15		

Exposure Duration: CHRONIC

Equations:
ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table D-7a
Subchronic Risk and Hazard Estimates for the Offsite Infant Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral [c]	Dermal [c]	Inhalation (ambient)			Oral [c]	Dermal [c]	Inhalation (ambient)		
Metals														
Arsenic	7.6E+00	1.3E+09	5.8E-09				1.3E-10	1.3E-10	9%			1.4E-04	1.4E-04	21.3%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08				-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05				-		-			-		-
Lead									-					-
Nickel	2.0E+01	1.3E+09	1.5E-08				2.1E-11	2.1E-11	1%			6.3E-05	6.3E-05	9.4%
VOCs														
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06	V			-		-			1.2E-04	1.2E-04	17.3%
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06	V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05	V			5.5E-10	5.5E-10	38%			6.2E-05	6.2E-05	9.2%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05	V			-		-			1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05	V			4.7E-10	4.7E-10	33%			1.5E-06	1.5E-06	<1%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05	V			6.4E-11	6.4E-11	4%			3.2E-06	3.2E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04	V			-		-			2.4E-05	2.4E-05	3.6%
Toluene	8.2E-02	4.6E+03	1.8E-05	V			-		-			1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04	V			-		-			1.1E-04	1.1E-04	16.3%
SVOCs														
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06	V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06	V			-		-			-		-
PAHs														
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11				*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11				*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11				*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11				*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11				*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11				*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11				*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06	V			2.1E-10	2.1E-10	15%			1.5E-04	1.5E-04	21.8%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11				1.4E-13	1.4E-13	<1%			-		-
Miscellaneous														
Sulfolane	3.8E-02	1.3E+09	2.9E-11				-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09				-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07				-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06				-		-			-		-
Total Risk or Hazard					0E+00	0E+00	1E-09	1E-09		0E+00	0E+00	7E-04	7E-04	
Total Risk or Hazard Excluding Arsenic					0E+00	0E+00	1E-09	1E-09		0E+00	0E+00	5E-04	5E-04	

Table D-7a

Subchronic Risk and Hazard Estimates for the Offsite Infant Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	mg/m$^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m³/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

INF_ATc	25550	Exposure Duration	SUBCHRONIC
INF_ATnc	365	INF_ET	12
INF_AF	–	INF_FI	–
INF_BW	6.75	INF_IRs	–
INF_ED	1	INF_PEF	1316000000
INF_EF	270	INF_SA	–

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table D-7b
Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - All Offsite Wells - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	4.4E-01					-			-	-	6.6E+00			6.6E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		7E+00	0E+00	0E+00	7E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table D-7c
Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - All Offsite Wells - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK: Route-Specific Risk Ingestion (fruit)	CANCER RISK: Route-Specific Risk Ingestion (vegetables)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	4.4E-01	1.0E+00	4.4E-01	-	-		-	1.9E-01	1.3E-01	3.2E-01	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		2E-01	1E-01	3E-01	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_IRPfr	155250
INF_ATnc	365	INF_IRPvg	109350
INF_ED	1	INF_FIp	0.25
INF_EF	270		
INF_BW	6.75		

Exposure Duration SUBCHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table D-8
Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - All Offsite Wells - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] (L/cm²/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK: Route-Specific Risk: Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard: Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	4.4E-01					-			-	-	8.7E+00			8.7E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		9E+00	0E+00	0E+00	9E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm²/event)	L/cm²/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m³)	mg/m³:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m³)	VF:	Volatilization factor (m³/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m³)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-9a

Chronic Risk and Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral [c]	Dermal [c]	Inhalation (ambient)			Oral [c]	Dermal [c]	Inhalation (ambient)		
Metals														
Arsenic	7.6E+00	1.3E+09	5.8E-09				2.0E-09	2.0E-09	9%			8.8E-05	8.8E-05	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08				-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05				-		-			-		-
Lead									-					-
Nickel	2.0E+01	1.3E+09	1.5E-08				3.3E-10	3.3E-10	1%			3.9E-05	3.9E-05	6.0%
VOCs														
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06	V			-		-			-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06	V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05	V			8.5E-09	8.5E-09	38%			1.0E-04	1.0E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05	V			-		-			1.0E-06	1.0E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05	V			7.3E-09	7.3E-09	33%			8.2E-06	8.2E-06	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05	V			9.8E-10	9.8E-10	4%			5.8E-06	5.8E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04	V			-		-			4.2E-05	4.2E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05	V			-		-			8.1E-07	8.1E-07	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04	V			-		-			2.7E-04	2.7E-04	41.7%
SVOCs														
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06	V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06	V			-		-			-		-
PAHs														
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11				*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11				*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11				*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11				*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11				*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11				*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11				*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06	V			3.3E-09	3.3E-09	15%			9.0E-05	9.0E-05	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11				2.2E-12	2.2E-12	<1%			-		-
Miscellaneous														
Sulfolane	3.8E-02	1.3E+09	2.9E-11				-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09				-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07				-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06				-		-			-		-
Total Risk or Hazard					0E+00	0E+00	2E-08	2E-08		0E+00	0E+00	6E-04	6E-04	
Total Risk or Hazard Excluding Arsenic					0E+00	0E+00	2E-08	2E-08		0E+00	0E+00	6E-04	6E-04	

Table D-9a

Chronic Risk and Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	mg/m$^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m³/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

		Exposure Duration	CHRONIC
CIo_ATc	25550	CIo_ET	8
CIo_ATnc	9125	CIo_FI	1
CIo_BW	70	CIo_IRs	100
CIo_ED	25	CIo_PEF	1316000000
CIo_EF	250		

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table D-9b
Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - All Offsite Wells - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	4.4E-01					-			-	-	8.7E+00			8.7E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		9E+00	0E+00	0E+00	9E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CIo_ATC	25550	CIo_ETgwi	–
CIo_ATnc	9125	CIo_EvFgw	–
CIo_BW	70	CIo_FIgw	1
CIo_ED	25	CIo_IRgw	2
CIo_EFgw	250	CIo_Sagw	–
CIo_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table D-10
Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - All Offsite Wells - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral	Dermal [c]	Inhalation (domestic use) [c]			Oral	Dermal [c]	Inhalation (domestic use) [c]		
Miscellaneous														
Sulfolane	4.4E-01		2.0E-07		-			-	-	8.0E-04			8.0E-04	100%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		8E-04	0E+00	0E+00	8E-04	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:
[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CST_ATC	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_FIgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Exposure Duration SUBCHRONIC

Equations:

$$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$$

$$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$$

Table D-11
Chronic Hazard Estimates for the Offsite Adult Recreator Exposed to Surface Water - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCsw (mg/L)	VF [a] (L/m^3)	DA [b] (L/cm^2/event)	CANCER RISK: Route-Specific Risk Oral [c]	Dermal [d]	Inhalation [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [d]	Inhalation [d]	Calculated Hazard	Percent Total HI
Miscellaneous													
Sulfolane	1.6E-01			-			-	-	2.6E-02			2.6E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00	0E+00		3E-02	0E+00	0E+00	3E-02	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCsw:	Exposure point concentration in surface water (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTsw) as shown for this receptor below.
[c] This exposure scenario assumes recreational contact exposures including swimming, walking, wading, and splashing.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions): Exposure Duration CHRONIC

AREC_ATC	25550	AREC_ET	1
AREC_ATnc	10950	AREC_EvFsw	–
AREC_BW	70	AREC_FIsw	1
AREC_ED	30	AREC_IRinc_sw	0.071
AREC_EFsw	60	AREC_SAsw	–
AREC_EvTsw	–		

Equations:

$ELCRo = (EPCsw \times FIsw \times IRinc\_sw \times ET \times EFsw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCsw \times FIsw \times IRinc\_sw \times ET \times EFsw \times ED) / (BW \times ATnc \times RfDo)$

Table D-12
Chronic Hazard Estimates for the Offsite Child Recreator Exposed to Surface Water - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCsw (mg/L)	VF [a] (L/m^3)	DA [b] (L/cm^2/event)	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
				Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
				Oral [c]	Dermal [d]	Inhalation [d]			Oral [c]	Dermal [d]	Inhalation [d]		
Miscellaneous													
Sulfolane	1.6E-01			-			-	-	2.1E-01			2.1E-01	100%
Total Risk or Hazard				0E+00	0E+00	0E+00	0E+00		2E-01	0E+00	0E+00	2E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCsw:	Exposure point concentration in surface water (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTsw) as shown for this receptor below.
[c] This exposure scenario assumes recreational contact exposures including swimming, walking, wading, and splashing.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CREC_ATC	25550	CREC_ET	1
CREC_ATnc	2190	CREC_EvFsw	–
CREC_BW	15	CREC_FIsw	1
CREC_ED	6	CREC_IRinc_sw	0.12
CREC_EFsw	60	CREC_SAsw	–
CREC_EvTsw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCsw \times FIsw \times IRinc\_sw \times ET \times EFsw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCsw \times FIsw \times IRinc\_sw \times ET \times EFsw \times ED) / (BW \times ATnc \times RfDo)$

Table D-13a
Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - Exposure Unit 2 - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.4E-01					-			-	-	3.9E+00			3.9E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		4E+00	0E+00	0E+00	4E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-13b
Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - Exposure Unit 2 - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK: Route-Specific Risk Ingestion (fruit)	CANCER RISK: Route-Specific Risk Ingestion (vegetables)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.4E-01	1.0E+00	1.4E-01	-	-		-	9.9E-02	1.6E-01	2.6E-01	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		1E-01	2E-01	3E-01	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_IRPfr	259000
ADUR_ATnc	10950	ADUR_IRPvg	413000
ADUR_ED	30	ADUR_FIp	0.25
ADUR_EF	270		
ADUR_BW	70		

Exposure Duration: CHRONIC

Equations:

$ELCRp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED \times CSF) / (1{,}000{,}000 \times BW \times ATC)$

$HIp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfD)$

Table D-14a
Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 2 - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.4E-01					-			-	-	9.2E+00			9.2E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		9E+00	0E+00	0E+00	9E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions): Exposure Duration CHRONIC

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-14b
Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 2 - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK			Percent Total ELCR	NON-CANCER HAZARD			Percent Total HI
				Route-Specific Risk		Calculated Risk		Route-Specific Hazard		Calculated Hazard	
				Ingestion (fruit)	Ingestion (vegetables)			Ingestion (fruit)	Ingestion (vegetables)		
Miscellaneous											
Sulfolane	1.4E-01	1.0E+00	1.4E-01	-	-		-	4.0E-01	3.6E-01	7.5E-01	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		4E-01	4E-01	8E-01	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_IRPfr	223500
CHR_ATnc	2190	CHR_IRPvg	201000
CHR_ED	6	CHR_FIp	0.25
CHR_EF	270		
CHR_BW	15		

Exposure Duration: CHRONIC

Equations:

$ELCRp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED \times CSF) / (1{,}000{,}000 \times BW \times ATC)$

$HIp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfD)$

Table D-15a
Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - Exposure Unit 2 - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.4E-01					-			-	-	2.2E+00			2.2E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E+00	0E+00	0E+00	2E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table D-15b
Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - Exposure Unit 2 - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK: Route-Specific Risk Ingestion (fruit)	CANCER RISK: Route-Specific Risk Ingestion (vegetables)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.4E-01	1.0E+00	1.4E-01	-	-		-	6.1E-02	4.3E-02	1.0E-01	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		6E-02	4E-02	1E-01	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_IRPfr	155250
INF_ATnc	365	INF_IRPvg	109350
INF_ED	1	INF_FIp	0.25
INF_EF	270		
INF_BW	6.75		

Exposure Duration SUBCHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table D-16
Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - Exposure Unit 2 - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] (L/cm²/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.4E-01					-			-	-	2.8E+00			2.8E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E+00	0E+00	0E+00	3E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm²/event)	L/cm²/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m³)	mg/m³:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m³)	VF:	Volatilization factor (m³/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m³)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions): Exposure Duration CHRONIC

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-17
Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - Exposure Unit 2 - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.4E-01					-			-	-	2.8E+00			2.8E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E+00	0E+00	0E+00	3E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions): Exposure Duration CHRONIC

CIo_ATC	25550	CIo_ETgwi	–
CIo_ATnc	9125	CIo_EvFgw	–
CIo_BW	70	CIo_FIgw	1
CIo_ED	25	CIo_IRgw	2
CIo_EFgw	250	CIo_Sagw	–
CIo_EvTgw	–		

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table D-18
Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - Exposure Unit 2 - Maximum COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral	Dermal [c]	Inhalation (domestic use) [c]			Oral	Dermal [c]	Inhalation (domestic use) [c]		
Miscellaneous														
Sulfolane	1.4E-01		2.0E-07		-			-	-	2.6E-04			2.6E-04	100%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		3E-04	0E+00	0E+00	3E-04	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	mg/m^3:	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:
[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CST_ATC	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_FIgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Exposure Duration SUBCHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-19a
Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - Exposure Unit 3 - Maximum COPC Concentrations
Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	8.0E-02					-			-	-	2.2E+00			2.2E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E+00	0E+00	0E+00	2E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-19b
Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - Exposure Unit 3 - Maximum COPC Concentrations
Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK: Route-Specific Risk Ingestion (fruit)	CANCER RISK: Route-Specific Risk Ingestion (vegetables)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	8.0E-02	1.0E+00	8.0E-02	-	-		-	5.5E-02	8.8E-02	1.4E-01	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		5E-02	9E-02	1E-01	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_IRPfr	259000
ADUR_ATnc	10950	ADUR_IRPvg	413000
ADUR_ED	30	ADUR_FIp	0.25
ADUR_EF	270		
ADUR_BW	70		

Exposure Duration CHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table D-20a
Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 3 - Maximum COPC Concentrations
Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	8.0E-02					-			-	-	5.1E+00			5.1E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		5E+00	0E+00	0E+00	5E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-20b
Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 3 - Maximum COPC Concentrations
Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK			Percent Total ELCR	NON-CANCER HAZARD			Percent Total HI
				Route-Specific Risk		Calculated Risk		Route-Specific Hazard		Calculated Hazard	
				Ingestion (fruit)	Ingestion (vegetables)			Ingestion (fruit)	Ingestion (vegetables)		
Miscellaneous											
Sulfolane	8.0E-02	1.0E+00	8.0E-02	-	-		-	2.2E-01	2.0E-01	4.2E-01	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		2E-01	2E-01	4E-01	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	Exposure Duration	CHRONIC
CHR_ATnc	2190	CHR_IRPfr	223500
CHR_ED	6	CHR_IRPvg	201000
CHR_EF	270	CHR_FIp	0.25
CHR_BW	15		

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table D-21a
Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - Exposure Unit 3 - Maximum COPC Concentrations
Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	8.0E-02					-			-	-	1.2E+00			1.2E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		1E+00	0E+00	0E+00	1E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table D-21b
Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - Exposure Unit 3 - Maximum COPC Concentrations
Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK			Percent Total ELCR	NON-CANCER HAZARD			Percent Total HI
				Route-Specific Risk		Calculated Risk		Route-Specific Hazard		Calculated Hazard	
				Ingestion (fruit)	Ingestion (vegetables)			Ingestion (fruit)	Ingestion (vegetables)		
Miscellaneous											
Sulfolane	8.0E-02	1.0E+00	8.0E-02	-	-		-	3.4E-02	2.4E-02	5.8E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		3E-02	2E-02	6E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_IRPfr	155250
INF_ATnc	365	INF_IRPvg	109350
INF_ED	1	INF_FIp	0.25
INF_EF	270		
INF_BW	6.75		

Exposure Duration SUBCHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table D-22
Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - Exposure Unit 3 - Maximum COPC Concentrations
Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] (L/cm^2/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	8.0E-02					-			-	-	1.6E+00			1.6E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E+00	0E+00	0E+00	2E+00	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-23
Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - Exposure Unit 3 - Maximum COPC Concentrations
Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	8.0E-02					-			-	-	1.6E+00			1.6E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E+00	0E+00	0E+00	2E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CIo_ATC	25550	CIo_ETgwi	–
CIo_ATnc	9125	CIo_EvFgw	–
CIo_BW	70	CIo_FIgw	1
CIo_ED	25	CIo_IRgw	2
CIo_EFgw	250	CIo_Sagw	–
CIo_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table D-24
Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - Exposure Unit 3 - Maximum COPC Concentrations
Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral	Dermal [c]	Inhalation (trench air) [c]			Oral	Dermal [c]	Inhalation (trench air) [c]		
Miscellaneous														
Sulfolane	8.0E-02		2.0E-07		-			-	-	1.5E-04			1.5E-04	100%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		1E-04	0E+00	0E+00	1E-04	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m³:	Liter(s) per cubic meter		

Notes:
[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CST_ATC	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_FIgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table D-25

Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Indoor Worker Exposed to Indoor Air - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (ug/L) [b]	EPCsg (mg/m^3) [a]	AF [a]	EPCia (mg/m^3) [a]		CANCER RISK: Route-Specific Risk Inhalation (indoor air)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Inhalation (indoor air)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Metals											
Barium	4.8E+02							-			-
Iron	5.7E+04							-			-
Lead	2.1E+00							-			-
VOCs											
1,2,4-Trimethylbenzene	6.1E+02	4.0E+01	1.1E-05	4.5E-04	V	-		-	1.5E-02	1.5E-02	8.0%
1,3,5-Trimethylbenzene	1.8E+02	1.1E+01	1.3E-05	1.4E-04	V	-		-	-		-
4-Isopropyltoluene (p-cymene)	6.0E+01				V			-			-
Benzene	1.9E+04	1.7E+03	1.0E-05	1.7E-02	V	1.1E-05	1.1E-05	93%	1.3E-01	1.3E-01	71.7%
Ethylbenzene	2.8E+03	2.7E+02	7.5E-06	2.1E-03	V	4.2E-07	4.2E-07	4%	4.7E-04	4.7E-04	<1%
n-Propylbenzene	1.2E+02	1.4E+01	6.5E-06	9.2E-05	V	-		-	2.1E-05	2.1E-05	<1%
Toluene	3.0E+04	2.9E+03	8.7E-06	2.5E-02	V	-		-	1.1E-03	1.1E-03	<1%
Xylenes	1.4E+04	1.4E+03	8.4E-06	1.1E-02	V	-		-	2.6E-02	2.6E-02	14.2%
SVOCs											
1-Methylnaphthalene	3.5E+01	1.1E-01	1.1E-04	1.2E-05	V	-		-	-		-
2-Methylnaphthalene	3.1E+01	9.7E-02	1.1E-04	1.1E-05	V	-		-	-		-
PAHs											
Naphthalene	3.0E+02	1.3E+00	9.4E-05	1.2E-04	V	3.4E-07	3.4E-07	3%	9.4E-03	9.4E-03	5.2%
Miscellaneous											
Sulfolane	1.0E+04							-			-
GRO	2.1E+04							-			-
DRO	2.2E+03							-			-
RRO	2.8E+02							-			-
Total Risk or Hazard						1E-05	1E-05		2E-01	2E-01	

Abbreviations:

-:	Not applicable	ug/L:	Microgram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCgw:	Exposure point concentration in groundwater (ug/L)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	SVOCs:	Semi-volatile organic compounds
EPCsg:	Exposure point concentration in soil gas (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
AF:	Attenuation factor (unitless)		

Table D-25

Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Indoor Worker Exposed to Indoor Air - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Notes:

[a] Modeled from groundwater data using Johnson & Ettinger Soil Gas Model (USEPA, 2004). A commercial air exchange rate of 1 per hour was used. Results presented in Appendix C.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CI_ATC	25550
CI_ATnc	9125
CI_ED	25
CI_EF	250
CI_ET	8

Exposure Duration CHRONIC

Equations:

ELCRia (VOCs) = ([EPCsg × AF] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQia (VOCs) = ([EPCsg × AF] × ET × EF × ED) / (24 × ATnc × RfC)

Table D-26

Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.6E+00	1.3E+09	5.8E-09			4.0E-06	5.3E-07	2.0E-09	4.5E-06	97%	2.5E-02	3.3E-03	8.8E-05	2.8E-02	52.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08			-	-	-	-	-	1.3E-05	-	-	1.3E-05	<1%
Iron	1.7E+04	1.3E+09	1.3E-05			-	-	-	-	-	2.4E-02	-	-	2.4E-02	44.3%
Lead							-			-		-			-
Nickel	2.0E+01	1.3E+09	1.5E-08			-	-	3.3E-10	3.3E-10	<1%	9.9E-04	-	3.9E-05	1.0E-03	1.9%
VOCs															
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V	-	-	-	-	-	2.2E-06	-	-	2.2E-06	<1%
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V	-	-	-	-	-	-	-	-	-	-
Benzene	5.1E-02	3.8E+03	1.3E-05		V	9.8E-10	-	8.5E-09	9.5E-09	<1%	1.2E-05	-	1.0E-04	1.1E-04	<1%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V	-	-	-	-	-	-	-	1.0E-06	1.0E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V	8.4E-10	-	7.3E-09	8.1E-09	<1%	2.1E-06	-	8.2E-06	1.0E-05	<1%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V	1.6E-10	-	9.8E-10	1.1E-09	<1%	9.8E-07	-	5.8E-06	6.8E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V	-	-	-	-	-	1.9E-06	-	4.2E-05	4.4E-05	<1%
Toluene	8.2E-02	4.6E+03	1.8E-05		V	-	-	-	-	-	1.0E-06	-	8.1E-07	1.8E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V	-	-	-	-	-	3.6E-06	-	2.7E-04	2.7E-04	<1%
SVOCs															
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V	2.5E-09	-	-	2.5E-09	<1%	3.4E-06	-	-	3.4E-06	<1%
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V	-	-	-	-	-	6.7E-05	-	-	6.7E-05	<1%
PAHs															
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11			*	*	*	*	-	-	-	-	-	-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11			*	*	*	*	-	-	-	-	-	-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11			*	*	*	*	-	-	-	-	-	-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11			*	*	*	*	-	-	-	-	-	-
Chrysene	6.6E-02	1.3E+09	5.0E-11			*	*	*	*	-	-	-	-	-	-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11			*	*	*	*	-	-	-	-	-	-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11			*	*	*	*	-	-	-	-	-	-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V	-	-	3.3E-09	3.3E-09	<1%	2.9E-06	1.7E-06	9.0E-05	9.5E-05	<1%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11			8.1E-08	4.7E-08	2.2E-12	1.3E-07	3%	-	-	-	-	-
Miscellaneous															
Sulfolane	3.8E-02	1.3E+09	2.9E-11			-	-	-	-	-	3.7E-06	-	-	3.7E-06	<1%
GRO	5.4E+00	1.3E+09	4.1E-09			-	-	-	-	-	-	-	-	-	-
DRO	2.1E+02	1.3E+09	1.6E-07			-	-	-	-	-	-	-	-	-	-
RRO	1.9E+03	1.3E+09	1.4E-06			-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard						4E-06	6E-07	2E-08	5E-06		5E-02	3E-03	6E-04	5E-02	
Total Risk or Hazard Excluding Arsenic						9E-08	5E-08	2E-08	2E-07		2E-02	2E-06	6E-04	3E-02	

Table D-26

Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

				Exposure Duration	CHRONIC
Clo_ATc	25550	Clo_ET	8		
Clo_ATnc	9125	Clo_EvFs	1		
Clo_AF	0.2	Clo_FI	1		
Clo_BW	70	Clo_IRs	100		
Clo_ED	25	Clo_PEF	1.316E+09		
Clo_EF	250	Clo_SA	2230		

Equations:

$ELCRo = (EPCs \times FI \times IRs \times EF \times ED \times CSFo) / (1{,}000{,}000 \times BW \times ATc)$

$ELCRd = ([EPCs \times AF \times ABSd] \times SA \times EvFs \times EF \times ED \times CSFd) / (1{,}000{,}000 \times BW \times ATc)$

$ELCRaa = ([EPCs / (VF \text{ or } PEF)] \times EF \times ED \times ET \times IUR \times 1000) / (24 \times ATc)$

$HQo = (EPCs \times FI \times IRs \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfDo)$

$HQd = ([EPCs \times AF \times ABSd]) \times SA \times EvFs \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfDa)$

$HQaa = ([EPCs / (VF \text{ or } PEF)] \times ET \times EF \times ED) / (24 \times ATnc \times RfC)$

Table D-27a

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Subsurface Soil (0 to 15 ft below ground surface) - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	1.8E+01	1.0E+06	1.8E-05			6.1E-07	3.7E-08	1.5E-08	6.6E-07	69%	5.7E-03	3.5E-04	1.7E-02	2.3E-02	8.2%
Chromium, Total	5.1E+01	1.0E+06	5.1E-05			-	-	-	-	-	5.5E-05	-	-	5.5E-05	<1%
Iron	2.9E+04	1.0E+06	2.9E-02			-	-	-	-	-	6.7E-02	-	-	6.7E-02	24.0%
Nickel	3.8E+01	1.0E+06	3.8E-05			-	-	2.0E-09	2.0E-09	<1%	3.1E-03	-	6.0E-03	9.1E-03	3.3%
VOCs															
1,2,4-Trimethylbenzene	2.1E+02	8.5E+03	2.4E-02		V	-	-	-	-	-	-	-	4.9E-03	4.9E-03	1.8%
1,3,5-Trimethylbenzene	8.1E+01	7.1E+03	1.1E-02		V	-	-	-	-	-	1.3E-03	-	1.6E-02	1.8E-02	6.3%
4-Isopropyltoluene (p-cymene)	2.0E+01	9.4E+03	2.2E-03		V	-	-	-	-	-	-	-	-	-	-
Benzene	8.2E+01	3.8E+03	2.2E-02		V	1.0E-07	-	3.4E-08	1.4E-07	14%	1.3E-02	-	3.8E-03	1.7E-02	6.1%
Cyclohexane	4.5E+01	1.1E+03	4.0E-02		V	-	-	-	-	-	-	-	9.5E-05	9.5E-05	<1%
Ethylbenzene	1.1E+02	6.1E+03	1.8E-02		V	2.8E-08	-	9.3E-09	3.7E-08	4%	3.6E-03	-	2.9E-05	3.6E-03	1.3%
Isopropylbenzene (cumene)	4.2E+01	6.7E+03	6.2E-03		V	-	-	-	-	-	1.7E-04	-	9.9E-04	1.2E-03	<1%
Methylene chloride	1.9E-01	2.4E+03	8.0E-05		V	3.3E-11	-	7.6E-12	4.0E-11	<1%	5.1E-06	-	3.8E-07	5.4E-06	<1%
n-Butylbenzene	1.1E+02	8.8E+03	1.2E-02		V	-	-	-	-	-	1.7E-03	-	-	1.7E-03	<1%
n-Hexane	1.3E+01	8.9E+02	1.5E-02		V	-	-	-	-	-	7.0E-05	-	1.0E-04	1.7E-04	<1%
n-Propylbenzene	7.3E+01	7.5E+03	9.7E-03		V	-	-	-	-	-	1.2E-03	2.4E-04	1.4E-04	1.5E-03	<1%
sec-Butylbenzene	2.5E+01	8.1E+03	3.1E-03		V	-	-	-	-	-	-	-	-	-	-
Toluene	3.9E+02	4.6E+03	8.5E-02		V	-	-	-	-	-	7.9E-04	-	2.4E-04	1.0E-03	<1%
Xylenes	7.1E+02	6.3E+03	1.1E-01		V	-	-	-	-	-	2.8E-03	-	4.0E-03	6.9E-03	2.5%
SVOCs															
1-Methylnaphthalene	8.9E+01	6.3E+04	1.4E-03		V	5.9E-08	-	-	5.9E-08	6%	2.0E-03	-	-	2.0E-03	<1%
2-Methylnaphthalene	2.4E+02	6.2E+04	3.8E-03		V	-	-	-	-	-	9.7E-02	-	-	9.7E-02	34.8%
PAHs															
Benzo (a) anthracene	9.9E-02	1.0E+06	9.9E-08			*	*	*	*	-	-	-	-	-	-
Benzo (a) pyrene	9.5E-02	1.0E+06	9.5E-08			*	*	*	*	-	-	-	-	-	-
Benzo (b) fluoranthene	1.1E-01	1.0E+06	1.1E-07			*	*	*	*	-	-	-	-	-	-
Benzo (k) fluoranthene	4.0E-02	1.0E+06	4.0E-08			*	*	*	*	-	-	-	-	-	-
Chrysene	7.8E-01	1.0E+06	7.8E-07			*	*	*	*	-	-	-	-	-	-
Dibenzo (a,h) anthracene	1.8E-02	1.0E+06	1.8E-08			*	*	*	*	-	-	-	-	-	-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.0E+06	6.9E-08			*	*	*	*	-	-	-	-	-	-
Naphthalene	1.3E+02	5.0E+04	2.5E-03		V	-	-	1.7E-08	1.7E-08	2%	1.0E-02	2.7E-03	1.2E-02	2.5E-02	8.9%
Total Benzo(a)pyrene TEQ	2.3E-01	1.0E+06	2.3E-07			3.8E-08	1.0E-08	5.0E-11	4.8E-08	5%	-	-	-	-	-
Miscellaneous															
Sulfolane	1.8E+01	1.0E+06	1.8E-05			-	-	-	-	-	3.0E-04	-	-	3.0E-04	<1%
GRO	7.7E+03	1.0E+06	7.7E-03			-	-	-	-	-	-	-	-	-	-
DRO	1.9E+04	1.0E+06	1.9E-02			-	-	-	-	-	-	-	-	-	-
RRO	6.5E+04	1.0E+06	6.5E-02			-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard						8E-07	5E-08	8E-08	1E-06		2E-01	3E-03	7E-02	3E-01	
Total Risk or Hazard Excluding Arsenic						2E-07	1E-08	6E-08	3E-07		2E-01	3E-03	5E-02	3E-01	

Table D-27a

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Subsurface Soil (0 to 15 ft below ground surface) - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	$mg/m^{3:}$	Milligram(s) per cubic meter
ELCR:	Excess lifetime cancer risk (unitless)	PAH:	Polycyclic aromatic hydrocarbon
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
mg/kg:	Milligram(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk
m^3/kg:	Cubic meter(s) per kilogram		

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CST_ATc	25550	CST_ET	1
CST_ATnc	365	CST_EvFs	1
CST_AF	0.3	CST_FI	1
CST_BW	70	CST_IRs	330
CST_ED	1	CST_PEF	1.00E+06
CST_EF	125	CST_SA	2230

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCs × FI × IRs × EF × ED × CSFo) / (1,000,000 × BW × ATc)

ELCRd = ([EPCs × AF × ABSd] × SA × EvFs × EF × ED × CSFd) / (1,000,000 × BW × ATc)

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCs × FI × IRs × EF × ED) / (1,000,000 × BW × ATnc × RfDo)

HQd = ([EPCs × AF ×ABSd]) × SA ×EvFs × EF × ED) / (1,000,000 × BW × ATnc × RfDa)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table D-27b

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Groundwater in a Trench - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCta [a] (mg/m3)		CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (trench air)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (trench air)	Calculated Hazard	Percent Total HI
Metals															
Barium	4.8E-01		1.0E-06			-	-	-	-	-	1.2E-04	1.1E-03		1.2E-03	<1%
Iron	5.7E+01		1.0E-06			-	-	-	-	-	1.5E-03	8.9E-04	-	2.4E-03	<1%
Lead	2.1E-03		1.0E-07			-	-	-	-	-	-	-	-	-	-
VOCs															
1,2,4-Trimethylbenzene	6.1E-01	7.5E+00	2.6E-04	4.6E+00	V	-	-	-	-	-	-	-	9.4E-01	9.4E-01	1.9%
1,3,5-Trimethylbenzene	1.8E-01	7.6E+00	1.8E-04	1.4E+00	V	-	-	-	-	-	3.3E-05	3.7E-03	2.0E+00	2.0E+00	4.1%
4-Isopropyltoluene (p-cymene)	6.0E-02	7.2E+00	5.0E-04	4.3E-01	V	-	-	-	-	-	-	-	-	-	-
Benzene	1.9E+01	9.3E+00	2.3E-05	1.7E+02	V	2.6E-07	3.7E-06	2.7E-04	2.8E-04	92%	3.3E-02	4.7E-01	3.1E+01	3.1E+01	64.4%
Ethylbenzene	2.8E+00	8.0E+00	8.8E-05	2.2E+01	V	7.8E-09	4.1E-07	1.1E-05	1.2E-05	4%	1.0E-03	5.3E-02	3.5E-02	8.9E-02	<1%
n-Propylbenzene	1.2E-01	7.6E+00	2.8E-04	9.2E-01	V	-	-	-	-	-	2.2E-05	3.8E-03	1.3E-02	1.7E-02	<1%
Toluene	3.0E+01	8.6E+00	5.2E-05	2.6E+02	V	-	-	-	-	-	6.8E-04	2.1E-02	7.4E-01	7.6E-01	1.6%
Xylenes	1.4E+01	8.0E+00	9.5E-05	1.1E+02	V	-	-	-	-	-	6.4E-04	3.6E-02	4.0E+00	4.1E+00	8.4%
SVOCs															
1-Methylnaphthalene	3.5E-02	6.3E+00	3.3E-04	2.2E-01	V	2.6E-10	5.2E-08	-	5.2E-08	<1%	9.1E-06	1.8E-03	-	1.8E-03	<1%
2-Methylnaphthalene	3.1E-02	6.3E+00	3.2E-04	2.0E-01	V	-	-	-	-	-	1.4E-04	2.7E-02	-	2.7E-02	<1%
PAHs															
Naphthalene	3.0E-01	6.6E+00	9.7E-05	2.0E+00	V	-	-	1.4E-05	1.4E-05	5%	2.7E-04	1.6E-02	9.4E+00	9.4E+00	19.4%
Miscellaneous															
Sulfolane	1.0E+01		2.0E-07			-	-	-	-	-	1.9E-03	2.3E-04	-	2.1E-03	<1%
GRO	2.1E+01		NA			-	-	-	-	-	-	-	-	-	-
DRO	2.2E+00		NA			-	-	-	-	-	-	-	-	-	-
RRO	2.8E-01		NA			-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard						3E-07	4E-06	3E-04	3E-04		4E-02	6E-01	4.8E+01	4.9E+01	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Table D-27b

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Groundwater in a Trench - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Notes:

[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

Parameters (see Table 3-12a for definitions):

CST_ATc	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_Flgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCgw × Flgw × IRinc_gw × EFgw × ED × CSFo) / (BW × ATc)

ELCRd = (EPCgw × DA × SAgw × EvFgw × EFgw × ED × CSFd) / (BW × ATc)

ELCRta (VOCs) = ([EPCgw × VF] × EFgw × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCgw × Flgw × IRinc_gw × EFgw × ED) / (BW × ATnc × RfDo)

HQd = (EPCgw × DA ×SAgw ×EvFgw × EFgw × ED) / (BW × ATnc × RfDa)

HQta (VOCs) = ([EPCgw × VF] × ET × EFgw × ED) / (24 × ATnc × RfC)

Table D-28

Chronic Risk and Hazard Estimates for the Onsite Adult Visitor Exposed to Indoor Air - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (ug/L) [b]	EPCsg (mg/m^3) [a]	AF [a]	EPCia (mg/m^3) [a]		CANCER RISK: Route-Specific Risk Inhalation (indoor air)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Inhalation (indoor air)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Metals											
Barium	4.8E+02							-			-
Iron	5.7E+04							-			-
Lead	2.1E+00							-			-
VOCs											
1,2,4-Trimethylbenzene	6.1E+02	4.0E+01	1.1E-05	4.5E-04	V	-		-	1.7E-04	1.7E-04	8.0%
1,3,5-Trimethylbenzene	1.8E+02	1.1E+01	1.3E-05	1.4E-04	V	-		-	-		-
4-Isopropyltoluene (p-cymene)	6.0E+01				V			-			-
Benzene	1.9E+04	1.7E+03	1.0E-05	1.7E-02	V	1.6E-07	1.6E-07	93%	1.6E-03	1.6E-03	71.7%
Ethylbenzene	2.8E+03	2.7E+02	7.5E-06	2.1E-03	V	6.1E-09	6.1E-09	4%	5.7E-06	5.7E-06	<1%
n-Propylbenzene	1.2E+02	1.4E+01	6.5E-06	9.2E-05	V	-		-	2.5E-07	2.5E-07	<1%
Toluene	3.0E+04	2.9E+03	8.7E-06	2.5E-02	V	-		-	1.4E-05	1.4E-05	<1%
Xylenes	1.4E+04	1.4E+03	8.4E-06	1.1E-02	V	-		-	3.1E-04	3.1E-04	14.2%
SVOCs											
1-Methylnaphthalene	3.5E+01	1.1E-01	1.1E-04	1.2E-05	V	-		-	-		-
2-Methylnaphthalene	3.1E+01	9.7E-02	1.1E-04	1.1E-05	V	-		-	-		-
PAHs											
Naphthalene	3.0E+02	1.3E+00	9.4E-05	1.2E-04	V	5.0E-09	5.0E-09	3%	1.1E-04	1.1E-04	5.2%
Miscellaneous											
Sulfolane	1.0E+04							-			-
GRO	2.1E+04							-			-
DRO	2.2E+03							-			-
RRO	2.8E+02							-			-
Total Risk or Hazard						2E-07	2E-07		2E-03	2E-03	

Abbreviations:

-:	Not applicable	ug/L:	Microgram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCgw:	Exposure point concentration in groundwater (ug/L)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	SVOCs:	Semi-volatile organic compounds
EPCsg:	Exposure point concentration in soil gas (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
AF:	Attenuation factor (unitless)		

Table D-28
Chronic Risk and Hazard Estimates for the Onsite Adult Visitor Exposed to Indoor Air - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Notes:

[a] Modeled from groundwater data using Johnson & Ettinger Soil Gas Model (USEPA, 2004). A commercial air exchange rate of 1 per hour was used. Results presented in Appendix C.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

VIS_ATC	25550
VIS_ATnc	10950
VIS_ED	30
VIS_EF	12
VIS_ET	2

Exposure Duration CHRONIC

Equations:

ELCRia (VOCs) = ([EPCsg × AF] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQia (VOCs) = ([EPCsg × AF] × ET × EF × ED) / (24 × ATnc × RfC)

Table D-29a

Chronic Risk and Hazard Estimates for the Offsite Adult Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.6E+00	1.3E+09	5.8E-09					3.9E-09	3.9E-09	9%			1.4E-04	1.4E-04	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08					-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05					-		-			-		-
Lead										-					-
Nickel	2.0E+01	1.3E+09	1.5E-08					6.3E-10	6.3E-10	1%			6.3E-05	6.3E-05	6.0%
VOCs															
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V			-		-			-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05		V			1.6E-08	1.6E-08	38%			1.6E-04	1.6E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V			-		-			1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V			1.4E-08	1.4E-08	33%			1.3E-05	1.3E-05	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V			1.9E-09	1.9E-09	4%			9.5E-06	9.5E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V			-		-			6.9E-05	6.9E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05		V			-		-			1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V			-		-			4.4E-04	4.4E-04	41.7%
SVOCs															
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V			-		-			-		-
PAHs															
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11					*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11					*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11					*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11					*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11					*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11					*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11					*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V			6.4E-09	6.4E-09	15%			1.5E-04	1.5E-04	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11					4.2E-12	4.2E-12	<1%			-		-
Miscellaneous															
Sulfolane	3.8E-02	1.3E+09	2.9E-11					-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09					-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07					-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06					-		-			-		-
Total Risk or Hazard						0E+00	0E+00	4E-08	4E-08		0E+00	0E+00	1E-03	1E-03	
Total Risk or Hazard Excluding Arsenic						0E+00	0E+00	4E-08	4E-08		0E+00	0E+00	9E-04	9E-04	

Table D-29a

Chronic Risk and Hazard Estimates for the Offsite Adult Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	mg/m$^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m³/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

ADUR_ATc	25550	ADUR_ET	12
ADUR_ATnc	10950	ADUR_FI	–
ADUR_AF	–	ADUR_IRs	–
ADUR_BW	70	ADUR_PEF	1316000000
ADUR_ED	30	ADUR_SA	–
ADUR_EF	270		

Exposure Duration CHRONIC

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table D-29b

Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - All Offsite Wells - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm^2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	4.4E-01					-			-	-	1.2E+00			1.2E+00	100.0%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		1.2E+00	0E+00	0E+00	1.2E+00	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-29c

Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - All Offsite Wells - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	4.4E-01	1.0E+00	4.4E-01	-	-		-	3.0E-02	4.8E-02	7.9E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		3.0E-02	4.8E-02	7.9E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_IRPfr	259000
ADUR_ATnc	10950	ADUR_IRPvg	413000
ADUR_ED	30	ADUR_Flp	0.25
ADUR_EF	270		
ADUR_BW	70		

Exposure Duration CHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table D-30a

Chronic Risk and Hazard Estimates for the Offsite Child Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR		NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals																
Arsenic	7.6E+00	1.3E+09	5.8E-09					7.9E-10	7.9E-10	9%				1.4E-04	1.4E-04	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08					-		-				-		-
Iron	1.7E+04	1.3E+09	1.3E-05					-		-				-		-
Lead										-						-
Nickel	2.0E+01	1.3E+09	1.5E-08					1.3E-10	1.3E-10	1%				6.3E-05	6.3E-05	6.0%
VOCs																
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V			-		-				-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V			-		-				-		-
Benzene	5.1E-02	3.8E+03	1.3E-05		V			3.3E-09	3.3E-09	38%				1.6E-04	1.6E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V			-		-				1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V			2.8E-09	2.8E-09	33%				1.3E-05	1.3E-05	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V			3.8E-10	3.8E-10	4%				9.5E-06	9.5E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V			-		-				6.9E-05	6.9E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05		V			-		-				1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V			-		-				4.4E-04	4.4E-04	41.7%
SVOCs																
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V			-		-				-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V			-		-				-		-
PAHs																
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11					*		-				-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11					*		-				-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11					*		-				-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11					*		-				-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11					*		-				-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11					*		-				-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11					*		-				-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V			1.3E-09	1.3E-09	15%				1.5E-04	1.5E-04	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11					8.4E-13	8.4E-13	<1%				-		-
Miscellaneous																
Sulfolane	3.8E-02	1.3E+09	2.9E-11					-		-				-		-
GRO	5.4E+00	1.3E+09	4.1E-09					-		-				-		-
DRO	2.1E+02	1.3E+09	1.6E-07					-		-				-		-
RRO	1.9E+03	1.3E+09	1.4E-06					-		-				-		-
Total Risk or Hazard						0E+00	0E+00	9E-09	9E-09			0E+00	0E+00	1E-03	1E-03	
Total Risk or Hazard Excluding Arsenic						0E+00	0E+00	8E-09	8E-09			0E+00	0E+00	9E-04	9E-04	

Table D-30a

Chronic Risk and Hazard Estimates for the Offsite Child Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

			Exposure Duration	CHRONIC
CHR_ATc	25550	CHR_ET	12	
CHR_ATnc	2190	CHR_FI	–	
CHR_AF	–	CHR_IRs	–	
CHR_BW	15	CHR_PEF	1316000000	
CHR_ED	6	CHR_SA	–	
CHR_EF	270			

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table D-30b

Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - All Offsite Wells - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm^2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	4.4E-01					-			-	-	2.8E+00			2.8E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2.8E+00	0E+00	0E+00	2.8E+00	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-30c

Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - All Offsite Wells - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	4.4E-01	1.0E+00	4.4E-01	-	-		-	1.2E-01	1.1E-01	2.3E-01	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		1E-01	1E-01	2E-01	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	Exposure Duration	CHRONIC
CHR_ATnc	2190	CHR_IRPfr	223500
CHR_ED	6	CHR_IRPvg	201000
CHR_EF	270	CHR_Flp	0.25
CHR_BW	15		

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table D-31a

Subchronic Risk and Hazard Estimates for the Offsite Infant Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR		NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals																
Arsenic	7.6E+00	1.3E+09	5.8E-09					1.3E-10	1.3E-10	9%				1.4E-04	1.4E-04	21.3%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08					-		-				-		-
Iron	1.7E+04	1.3E+09	1.3E-05					-		-				-		-
Lead										-						-
Nickel	2.0E+01	1.3E+09	1.5E-08					2.1E-11	2.1E-11	1%				6.3E-05	6.3E-05	9.4%
VOCs																
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V			-		-				1.2E-04	1.2E-04	17.3%
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V			-		-				-		-
Benzene	5.1E-02	3.8E+03	1.3E-05		V			5.5E-10	5.5E-10	38%				6.2E-05	6.2E-05	9.2%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V			-		-				1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V			4.7E-10	4.7E-10	33%				1.5E-06	1.5E-06	<1%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V			6.4E-11	6.4E-11	4%				3.2E-06	3.2E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V			-		-				2.4E-05	2.4E-05	3.6%
Toluene	8.2E-02	4.6E+03	1.8E-05		V			-		-				1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V			-		-				1.1E-04	1.1E-04	16.3%
SVOCs																
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V			-		-				-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V			-		-				-		-
PAHs																
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11					*		-				-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11					*		-				-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11					*		-				-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11					*		-				-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11					*		-				-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11					*		-				-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11					*		-				-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V			2.1E-10	2.1E-10	15%				1.5E-04	1.5E-04	21.8%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11					1.4E-13	1.4E-13	<1%				-		-
Miscellaneous																
Sulfolane	3.8E-02	1.3E+09	2.9E-11					-		-				-		-
GRO	5.4E+00	1.3E+09	4.1E-09					-		-				-		-
DRO	2.1E+02	1.3E+09	1.6E-07					-		-				-		-
RRO	1.9E+03	1.3E+09	1.4E-06					-		-				-		-
Total Risk or Hazard						0E+00	0E+00	1E-09	1E-09			0E+00	0E+00	7E-04	7E-04	
Total Risk or Hazard Excluding Arsenic						0E+00	0E+00	1E-09	1E-09			0E+00	0E+00	5E-04	5E-04	

Table D-31a

Subchronic Risk and Hazard Estimates for the Offsite Infant Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

INF_ATc	25550	INF_ET	12
INF_ATnc	365	INF_FI	–
INF_AF	–	INF_IRs	–
INF_BW	6.75	INF_PEF	1316000000
INF_ED	1	INF_SA	–
INF_EF	270		

Exposure Duration SUBCHRONIC

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table D-31b

Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - All Offsite Wells - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	4.4E-01					-			-	-	6.6E-01			6.6E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		7E-01	0E+00	0E+00	7E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

Exposure Duration SUBCHRONIC

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-31c

Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - All Offsite Wells - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	4.4E-01	1.0E+00	4.4E-01	-	-		-	1.9E-02	1.3E-02	3.2E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		2E-02	1E-02	3E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_IRPfr	155250
INF_ATnc	365	INF_IRPvg	109350
INF_ED	1	INF_Flp	0.25
INF_EF	270		
INF_BW	6.75		

Exposure Duration SUBCHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table D-32

Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - All Offsite Wells - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] (L/cm²/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	4.4E-01					-			-	-	8.7E-01			8.7E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		9E-01	0E+00	0E+00	9E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm²/event)	L/cm²/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m³)	mg/m³:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m³)	VF:	Volatilization factor (m³/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m³)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table D-33a

Chronic Risk and Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.6E+00	1.3E+09	5.8E-09					2.0E-09	2.0E-09	9%			8.8E-05	8.8E-05	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08					-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05					-		-			-		-
Lead										-					-
Nickel	2.0E+01	1.3E+09	1.5E-08					3.3E-10	3.3E-10	1%			3.9E-05	3.9E-05	6.0%
VOCs															
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V			-		-			-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05		V			8.5E-09	8.5E-09	38%			1.0E-04	1.0E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V			-		-			1.0E-06	1.0E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V			7.3E-09	7.3E-09	33%			8.2E-06	8.2E-06	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V			9.8E-10	9.8E-10	4%			5.8E-06	5.8E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V			-		-			4.2E-05	4.2E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05		V			-		-			8.1E-07	8.1E-07	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V			-		-			2.7E-04	2.7E-04	41.7%
SVOCs															
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V			-		-			-		-
PAHs															
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11					*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11					*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11					*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11					*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11					*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11					*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11					*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V			3.3E-09	3.3E-09	15%			9.0E-05	9.0E-05	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11					2.2E-12	2.2E-12	<1%			-		-
Miscellaneous															
Sulfolane	3.8E-02	1.3E+09	2.9E-11					-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09					-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07					-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06					-		-			-		-
Total Risk or Hazard						0E+00	0E+00	2E-08	2E-08		0E+00	0E+00	6E-04	6E-04	
Total Risk or Hazard Excluding Arsenic						0E+00	0E+00	2E-08	2E-08		0E+00	0E+00	6E-04	6E-04	

Table D-33a

Chronic Risk and Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

		Exposure Duration	CHRONIC
CIo_ATc	25550	CIo_ET	8
CIo_ATnc	9125	CIo_FI	1
CIo_BW	70	CIo_IRs	100
CIo_ED	25	CIo_PEF	1316000000
CIo_EF	250		

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table D-33b

Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - All Offsite Wells - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	4.4E-01					-			-	-	8.7E-01			8.7E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		9E-01	0E+00	0E+00	9E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CIo_ATC	25550	CIo_ETgwi	–
CIo_ATnc	9125	CIo_EvFgw	–
CIo_BW	70	CIo_FIgw	1
CIo_ED	25	CIo_IRgw	2
CIo_EFgw	250	CIo_Sagw	–
CIo_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table D-34

Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - All Offsite Wells - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK: Route-Specific Risk Oral	Dermal [c]	Inhalation (domestic use) [c]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal [c]	Inhalation (domestic use) [c]	Calculated Hazard	Percent Total HI
Miscellaneous														
Sulfolane	4.4E-01		2.0E-07		-			-	-	8.0E-05			8.0E-05	100%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		8E-05	0E+00	0E+00	8E-05	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:

[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

Exposure Duration SUBCHRONIC

CST_ATC	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_Flgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Equations:

$ELCRo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-35

Chronic Hazard Estimates for the Offsite Adult Recreator Exposed to Surface Water - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCsw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	CANCER RISK Route-Specific Risk Oral [c]	Dermal [d]	Inhalation [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral [c]	Dermal [d]	Inhalation [d]	Calculated Hazard	Percent Total HI
Miscellaneous													
Sulfolane	1.6E-01			-			-	-	2.6E-03			2.6E-03	100%
Total Risk or Hazard				0E+00	0E+00	0E+00	0E+00		3E-03	0E+00	0E+00	3E-03	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCsw:	Exposure point concentration in surface water (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTsw) as shown for this receptor below.
[c] This exposure scenario assumes recreational contact exposures including swimming, walking, wading, and splashing.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

AREC_ATC	25550	AREC_ET	1
AREC_ATnc	10950	AREC_EvFsw	–
AREC_BW	70	AREC_FIsw	1
AREC_ED	30	AREC_IRinc_sw	0.071
AREC_EFsw	60	AREC_SAsw	–
AREC_EvTsw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCsw × FIsw × IRinc_sw × ET × EFsw × ED × CSFo) / (BW × ATc)

HQo = (EPCsw × FIsw × IRinc_sw × ET × EFsw × ED) / (BW × ATnc × RfDo)

Table D-36

Chronic Hazard Estimates for the Offsite Child Recreator Exposed to Surface Water - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCsw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	CANCER RISK Route-Specific Risk Oral [c]	Dermal [d]	Inhalation [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral [c]	Dermal [d]	Inhalation [d]	Calculated Hazard	Percent Total HI
Miscellaneous													
Sulfolane	1.6E-01			-			-	-	2.1E-02			2.1E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00	0E+00		2E-02	0E+00	0E+00	2E-02	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCsw:	Exposure point concentration in surface water (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTsw) as shown for this receptor below.

[c] This exposure scenario assumes recreational contact exposures including swimming, walking, wading, and splashing.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CREC_ATC	25550	CREC_ET	1
CREC_ATnc	2190	CREC_EvFsw	–
CREC_BW	15	CREC_FIsw	1
CREC_ED	6	CREC_IRinc_sw	0.12
CREC_EFsw	60	CREC_SAsw	–
CREC_EvTsw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCsw × FIsw × IRinc_sw × ET × EFsw × ED × CSFo) / (BW × ATc)

HQo = (EPCsw × FIsw × IRinc_sw × ET × EFsw × ED) / (BW × ATnc × RfDo)

Table D-37a

Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - Exposure Unit 2 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.4E-01					-			-	-	3.9E-01			3.9E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		4E-01	0E+00	0E+00	4E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-37b

Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - Exposure Unit 2 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.4E-01	1.0E+00	1.4E-01	-	-		-	9.9E-03	1.6E-02	2.6E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		1E-02	2E-02	3E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_IRPfr	259000
ADUR_ATnc	10950	ADUR_IRPvg	413000
ADUR_ED	30	ADUR_Flp	0.25
ADUR_EF	270		
ADUR_BW	70		

Exposure Duration CHRONIC

Equations:

$ELCRp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times Flp \times EF \times ED \times CSF) / (1{,}000{,}000 \times BW \times ATC)$

$HIp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times Flp \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfD)$

Table D-38a

Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 2 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.4E-01					-			-	-	9.2E-01			9.2E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		9E-01	0E+00	0E+00	9E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions): Exposure Duration CHRONIC

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-38b

Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 2 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.4E-01	1.0E+00	1.4E-01	-	-		-	4.0E-02	3.6E-02	7.5E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		4E-02	4E-02	8E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_IRPfr	223500
CHR_ATnc	2190	CHR_IRPvg	201000
CHR_ED	6	CHR_Flp	0.25
CHR_EF	270		
CHR_BW	15		

Exposure Duration CHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table D-39a

Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - Exposure Unit 2 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.4E-01					-			-	-	2.2E-01			2.2E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-01	0E+00	0E+00	2E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions): Exposure Duration SUBCHRONIC

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-39b
Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - Exposure Unit 2 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.4E-01	1.0E+00	1.4E-01	-	-		-	6.1E-03	4.3E-03	1.0E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		6E-03	4E-03	1E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_IRPfr	155250
INF_ATnc	365	INF_IRPvg	109350
INF_ED	1	INF_Flp	0.25
INF_EF	270		
INF_BW	6.75		

Exposure Duration: SUBCHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table D-40

Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - Exposure Unit 2 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] (L/cm^2/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.4E-01					-			-	-	2.8E-01			2.8E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E-01	0E+00	0E+00	3E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions): Exposure Duration CHRONIC

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-41

Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - Exposure Unit 2 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm^2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.4E-01					-			-	-	2.8E-01			2.8E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E-01	0E+00	0E+00	3E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

Clo_ATC	25550	Clo_ETgwi	–
Clo_ATnc	9125	Clo_EvFgw	–
Clo_BW	70	Clo_Flgw	1
Clo_ED	25	Clo_IRgw	2
Clo_EFgw	250	Clo_Sagw	–
Clo_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × Flgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × Flgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table D-42

Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - Exposure Unit 2 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK: Route-Specific Risk Oral	Dermal [c]	Inhalation (domestic use) [c]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal [c]	Inhalation (domestic use) [c]	Calculated Hazard	Percent Total HI
Miscellaneous														
Sulfolane	1.4E-01		2.0E-07		-			-	-	2.6E-05			2.6E-05	100%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		3E-05	0E+00	0E+00	3E-05	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	mg/m^3:	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:

[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

Exposure Duration SUBCHRONIC

CST_ATC	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_Flgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Equations:

$ELCRo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-43a

Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - Exposure Unit 3 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	8.0E-02					-			-	-	2.2E-01			2.2E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-01	0E+00	0E+00	2E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table D-43b

Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - Exposure Unit 3 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	8.0E-02	1.0E+00	8.0E-02	-	-		-	5.5E-03	8.8E-03	1.4E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		5E-03	9E-03	1E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_IRPfr	259000
ADUR_ATnc	10950	ADUR_IRPvg	413000
ADUR_ED	30	ADUR_Flp	0.25
ADUR_EF	270		
ADUR_BW	70		

Exposure Duration CHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table D-44a

Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 3 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	8.0E-02					-			-	-	5.1E-01			5.1E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		5E-01	0E+00	0E+00	5E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table D-44b

Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 3 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	8.0E-02	1.0E+00	8.0E-02	-	-		-	2.2E-02	2.0E-02	4.2E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		2E-02	2E-02	4E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_IRPfr	223500
CHR_ATnc	2190	CHR_IRPvg	201000
CHR_ED	6	CHR_Flp	0.25
CHR_EF	270		
CHR_BW	15		

Exposure Duration CHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table D-45a

Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - Exposure Unit 3 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	8.0E-02					-			-	-	1.2E-01			1.2E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		1E-01	0E+00	0E+00	1E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table D-45b

Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - Exposure Unit 3 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	8.0E-02	1.0E+00	8.0E-02	-	-		-	3.4E-03	2.4E-03	5.8E-03	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		3E-03	2E-03	6E-03	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_IRPfr	155250
INF_ATnc	365	INF_IRPvg	109350
INF_ED	1	INF_Flp	0.25
INF_EF	270		
INF_BW	6.75		

Exposure Duration SUBCHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table D-46

Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - Exposure Unit 3 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] (L/cm^2/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	8.0E-02					-			-	-	1.6E-01			1.6E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-01	0E+00	0E+00	2E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-47

Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - Exposure Unit 3 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	8.0E-02					-			-	-	1.6E-01			1.6E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-01	0E+00	0E+00	2E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CIo_ATC	25550	CIo_ETgwi	–
CIo_ATnc	9125	CIo_EvFgw	–
CIo_BW	70	CIo_FIgw	1
CIo_ED	25	CIo_IRgw	2
CIo_EFgw	250	CIo_Sagw	–
CIo_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table D-48

Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - Exposure Unit 3 - Maximum COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral	Dermal [c]	Inhalation (trench air) [c]			Oral	Dermal [c]	Inhalation (trench air) [c]		
Miscellaneous														
Sulfolane	8.0E-02		2.0E-07		-			-	-	1.5E-05			1.5E-05	100%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		1E-05	0E+00	0E+00	1E-05	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	mg/m^3:	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:

[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

Exposure Duration SUBCHRONIC

CST_ATC	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_Flgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Equations:

$ELCRo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

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Appendix E

Estimated Risks/Hazards Using 95% UCL COPC Concentrations – PPRTV Scenario and ARCADIS Comparative Scenario

Table E-1
Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Indoor Worker Exposed to Indoor Air - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (ug/L) [b]	EPCsg (mg/m^3) [a]	AF [a]	EPCia (mg/m^3) [a]		CANCER RISK: Route-Specific Risk Inhalation (indoor air)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Inhalation (indoor air)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Metals											
Barium	2.6E+02							-			-
Iron	2.8E+04							-			-
Lead	1.2E+00							-			-
VOCs											
1,2,4-Trimethylbenzene	1.1E+02	7.3E+00	1.1E-05	8.2E-05	V	-		-	2.7E-03	2.7E-03	14.1%
1,3,5-Trimethylbenzene	1.2E+02	7.5E+00	1.3E-05	9.5E-05	V	-		-	-		-
4-Isopropyltoluene (p-cymene)	3.3E+01				V			-			-
Benzene	1.3E+03	1.2E+02	1.0E-05	1.2E-03	V	7.9E-07	7.9E-07	80%	9.4E-03	9.4E-03	49.7%
Ethylbenzene	1.8E+02	1.8E+01	7.5E-06	1.4E-04	V	2.8E-08	2.8E-08	3%	3.1E-05	3.1E-05	<1%
n-Propylbenzene	8.0E+01	9.4E+00	6.5E-06	6.0E-05	V	-		-	1.4E-05	1.4E-05	<1%
Toluene	1.4E+03	1.4E+02	8.7E-06	1.2E-03	V	-		-	5.4E-05	5.4E-05	<1%
Xylenes	1.2E+03	1.1E+02	8.4E-06	9.5E-04	V	-		-	2.2E-03	2.2E-03	11.5%
SVOCs											
1-Methylnaphthalene	3.5E+01	1.1E-01	1.1E-04	1.2E-05	V	-		-	-		-
2-Methylnaphthalene	2.5E+01	7.9E-02	1.1E-04	8.8E-06	V	-		-	-		-
PAHs											
Naphthalene	1.5E+02	6.3E-01	9.4E-05	6.0E-05	V	1.7E-07	1.7E-07	17%	4.6E-03	4.6E-03	24.1%
Miscellaneous											
Sulfolane	8.3E+02							-			-
GRO	2.1E+04							-			-
DRO	1.5E+03							-			-
RRO	2.8E+02							-			-
Total Risk or Hazard						1E-06	1E-06		2E-02	2E-02	

Abbreviations:

-:	Not applicable	ug/L:	Microgram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCgw:	Exposure point concentration in groundwater (ug/L)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	SVOCs:	Semi-volatile organic compounds
EPCsg:	Exposure point concentration in soil gas (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
AF:	Attenuation factor (unitless)		

Table E-1
Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Indoor Worker Exposed to Indoor Air - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Notes:

[a] Modeled from groundwater data using Johnson & Ettinger Soil Gas Model (USEPA, 2004). A commercial air exchange rate of 1 per hour was used. Results presented in Appendix C.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CI_ATC	25550
CI_ATnc	9125
CI_ED	25
CI_EF	250
CI_ET	8

Exposure Duration CHRONIC

Equations:

ELCRia (VOCs) = ([EPCsg × AF] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQia (VOCs) = ([EPCsg × AF] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-2
Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral	Dermal	Inhalation (ambient)			Oral	Dermal	Inhalation (ambient)		
Metals														
Arsenic	7.6E+00	1.3E+09	5.8E-09		4.0E-06	5.3E-07	2.0E-09	4.5E-06	97%	2.5E-02	3.3E-03	8.8E-05	2.8E-02	52.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08		-	-	-	-	-	1.3E-05	-	-	1.3E-05	<1%
Iron	1.7E+04	1.3E+09	1.3E-05		-	-	-	-	-	2.4E-02	-	-	2.4E-02	44.2%
Lead						-			-		-			-
Nickel	2.0E+01	1.3E+09	1.5E-08		-	-	3.3E-10	3.3E-10	<1%	9.9E-04	-	3.9E-05	1.0E-03	1.9%
VOCs														
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06	V	-	-	-	-	-	2.2E-06	-	-	2.2E-06	<1%
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06	V	-	-	-	-	-	-	-	-	-	-
Benzene	5.1E-02	3.8E+03	1.3E-05	V	9.8E-10	-	8.5E-09	9.5E-09	<1%	1.2E-05	-	1.0E-04	1.1E-04	<1%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05	V	-	-	-	-	-	-	-	1.0E-06	1.0E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05	V	8.4E-10	-	7.3E-09	8.1E-09	<1%	2.1E-06	-	8.2E-06	1.0E-05	<1%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05	V	1.6E-10	-	9.8E-10	1.1E-09	<1%	9.8E-07	-	5.8E-06	6.8E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04	V	-	-	-	-	-	1.9E-06	-	4.2E-05	4.4E-05	<1%
Toluene	8.2E-02	4.6E+03	1.8E-05	V	-	-	-	-	-	1.0E-06	-	8.1E-07	1.8E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04	V	-	-	-	-	-	3.6E-06	-	2.7E-04	2.7E-04	<1%
SVOCs														
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06	V	2.5E-09	-	-	2.5E-09	<1%	3.4E-06	-	-	3.4E-06	<1%
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06	V	-	-	-	-	-	6.7E-05	-	-	6.7E-05	<1%
PAHs														
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11		*	*	*	*	-	-	-	-	-	-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11		*	*	*	*	-	-	-	-	-	-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11		*	*	*	*	-	-	-	-	-	-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11		*	*	*	*	-	-	-	-	-	-
Chrysene	6.6E-02	1.3E+09	5.0E-11		*	*	*	*	-	-	-	-	-	-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11		*	*	*	*	-	-	-	-	-	-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11		*	*	*	*	-	-	-	-	-	-
Naphthalene	5.9E-02	5.0E+04	1.2E-06	V	-	-	3.3E-09	3.3E-09	<1%	2.9E-06	1.7E-06	9.0E-05	9.5E-05	<1%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11		8.1E-08	4.7E-08	2.2E-12	1.3E-07	3%	-	-	-	-	-
Miscellaneous														
Sulfolane	3.8E-02	1.3E+09	2.9E-11		-	-	-	-	-	3.7E-05	-	-	3.7E-05	<1%
GRO	5.4E+00	1.3E+09	4.1E-09		-	-	-	-	-	-	-	-	-	-
DRO	2.1E+02	1.3E+09	1.6E-07		-	-	-	-	-	-	-	-	-	-
RRO	1.9E+03	1.3E+09	1.4E-06		-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard					4E-06	6E-07	2E-08	5E-06		5E-02	3E-03	6E-04	5E-02	
Total Risk or Hazard Excluding Arsenic					9E-08	5E-08	2E-08	2E-07		2E-02	2E-06	6E-04	3E-02	

Table E-2
Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

				Exposure Duration	CHRONIC
Clo_ATc	25550		Clo_ET	8	
Clo_ATnc	9125		Clo_EvFs	1	
Clo_AF	0.2		Clo_FI	1	
Clo_BW	70		Clo_IRs	100	
Clo_ED	25		Clo_PEF	1316000000	
Clo_EF	250		Clo_SA	2230	

Equations:

ELCRo = (EPCs × FI × IRs × EF × ED × CSFo) / (1,000,000 × BW × ATc)
ELCRd = ([EPCs × AF × ABSd] × SA × EvFs × EF × ED × CSFd) / (1,000,000 × BW × ATc)
ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCs × FI × IRs × EF × ED) / (1,000,000 × BW × ATnc × RfDo)
HQd = ([EPCs × AF ×ABSd]) × SA ×EvFs × EF × ED) / (1,000,000 × BW × ATnc × RfDa)
HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-3a

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Subsurface Soil (0 to 15 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral	Dermal	Inhalation (ambient)			Oral	Dermal	Inhalation (ambient)		
Metals														
Arsenic	7.3E+00	1.0E+06	7.3E-06		2.5E-07	1.5E-08	6.4E-09	2.7E-07	94%	2.4E-03	1.4E-04	7.0E-03	9.5E-03	16.5%
Chromium, Total	1.7E+01	1.0E+06	1.7E-05		-	-	-	-	-	1.8E-05	-	-	1.8E-05	<1%
Iron	1.5E+04	1.0E+06	1.5E-02		-	-	-	-	-	3.5E-02	-	-	3.5E-02	60.4%
Nickel	1.9E+01	1.0E+06	1.9E-05		-	-	1.0E-09	1.0E-09	<1%	1.5E-03	-	3.0E-03	4.5E-03	7.9%
VOCs														
1,2,4-Trimethylbenzene	2.2E+01	8.5E+03	2.6E-03	V	-	-	-	-	-	-	-	5.3E-04	5.3E-04	<1%
1,3,5-Trimethylbenzene	8.3E+00	7.1E+03	1.2E-03	V	-	-	-	-	-	1.3E-04	-	1.7E-03	1.8E-03	3.1%
4-Isopropyltoluene (p-cymene)	2.0E+00	9.4E+03	2.2E-04	V	-	-	-	-	-	-	-	-	-	-
Benzene	3.1E+00	3.8E+03	8.2E-04	V	4.0E-09	-	1.3E-09	5.3E-09	2%	5.1E-04	-	1.5E-04	6.5E-04	1.1%
Cyclohexane	5.6E+00	1.1E+03	5.0E-03	V	-	-	-	-	-	-	-	1.2E-05	1.2E-05	<1%
Ethylbenzene	8.7E+00	6.1E+03	1.4E-03	V	2.2E-09	-	7.2E-10	2.9E-09	<1%	2.8E-04	-	2.3E-06	2.8E-04	<1%
Isopropylbenzene (cumene)	4.0E+00	6.7E+03	5.9E-04	V	-	-	-	-	-	1.6E-05	-	9.4E-05	1.1E-04	<1%
Methylene chloride	2.9E-01	2.4E+03	1.2E-04	V	5.0E-11	-	1.2E-11	6.2E-11	<1%	7.8E-06	-	5.8E-07	8.4E-06	<1%
n-Butylbenzene	7.6E+00	8.8E+03	8.7E-04	V	-	-	-	-	-	1.2E-04	-	-	1.2E-04	<1%
n-Hexane	2.4E+00	8.9E+02	2.7E-03	V	-	-	-	-	-	1.3E-05	-	1.9E-05	3.2E-05	<1%
n-Propylbenzene	7.2E+00	7.5E+03	9.6E-04	V	-	-	-	-	-	1.2E-04	2.4E-05	1.4E-05	1.5E-04	<1%
sec-Butylbenzene	6.6E+00	8.1E+03	8.1E-04	V	-	-	-	-	-	-	-	-	-	-
Toluene	1.7E+01	4.6E+03	3.8E-03	V	-	-	-	-	-	3.5E-05	-	1.1E-05	4.6E-05	<1%
Xylenes	4.7E+01	6.3E+03	7.5E-03	V	-	-	-	-	-	1.9E-04	-	2.7E-04	4.6E-04	<1%
SVOCs														
1-Methylnaphthalene	4.6E+00	6.3E+04	7.3E-05	V	3.1E-09	-	-	3.1E-09	1%	1.1E-04	-	-	1.1E-04	<1%
2-Methylnaphthalene	8.6E+00	6.2E+04	1.4E-04	V	-	-	-	-	-	3.5E-03	-	-	3.5E-03	6.0%
PAHs														
Benzo (a) anthracene	1.2E-02	1.0E+06	1.2E-08		*	*	*	*	-	-	-	-	-	-
Benzo (a) pyrene	1.2E-02	1.0E+06	1.2E-08		*	*	*	*	-	-	-	-	-	-
Benzo (b) fluoranthene	2.1E-02	1.0E+06	2.1E-08		*	*	*	*	-	-	-	-	-	-
Benzo (k) fluoranthene	1.9E-02	1.0E+06	1.9E-08		*	*	*	*	-	-	-	-	-	-
Chrysene	3.5E-02	1.0E+06	3.5E-08		*	*	*	*	-	-	-	-	-	-
Dibenzo (a,h) anthracene	9.9E-03	1.0E+06	9.9E-09		*	*	*	*	-	-	-	-	-	-
Indeno (1,2,3-cd) pyrene	1.1E-02	1.0E+06	1.1E-08		*	*	*	*	-	-	-	-	-	-
Naphthalene	4.4E+00	5.0E+04	8.8E-05	V	-	-	6.1E-10	6.1E-10	<1%	3.5E-04	9.3E-05	4.2E-04	8.6E-04	1.5%

Table E-3a
Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Subsurface Soil (0 to 15 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Total Benzo(a)pyrene TEQ	2.6E-02	1.0E+06	2.6E-08		4.3E-09	1.1E-09	5.8E-12	5.5E-09	2%	-	-	-	-	-
Miscellaneous														
Sulfolane	4.5E-01	1.0E+06	4.5E-07		-	-	-	-	-	7.3E-05	-	-	7.3E-05	<1%
GRO	8.1E+02	1.0E+06	8.1E-04		-	-	-	-	-	-	-	-	-	-
DRO	2.1E+03	1.0E+06	2.1E-03		-	-	-	-	-	-	-	-	-	-
RRO	8.2E+03	1.0E+06	8.2E-03		-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard					3E-07	2E-08	1E-08	3E-07		4E-02	3E-04	1E-02	6E-02	
Total Risk or Hazard Excluding Arsenic					1E-08	1E-09	4E-09	2E-08		4E-02	1E-04	6E-03	5E-02	

Abbreviations:

-:	Not applicable	mg/m^3:	Milligram(s) per cubic meter
ELCR:	Excess lifetime cancer risk (unitless)	PAH:	Polycyclic aromatic hydrocarbon
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
mg/kg:	Milligram(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk
m^3/kg:	Cubic meter(s) per kilogram		

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CST_ATc	25550	CST_ET	1
CST_ATnc	365	CST_EvFs	1
CST_AF	0.3	CST_FI	1
CST_BW	70	CST_IRs	330
CST_ED	1	CST_PEF	1.00E+06
CST_EF	125	CST_SA	2230

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCs × FI × IRs × EF × ED × CSFo) / (1,000,000 × BW × ATc)
ELCRd = ([EPCs × AF × ABSd] × SA × EvFs × EF × ED × CSFd) / (1,000,000 × BW × ATc)
ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCs × FI × IRs × EF × ED) / (1,000,000 × BW × ATnc × RfDo)
HQd = ([EPCs × AF ×ABSd]) × SA ×EvFs × EF × ED) / (1,000,000 × BW × ATnc × RfDa)
HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-3b
Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Groundwater in a Trench - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] (L/cm2/event	EPCta [a] (mg/m3)		CANCER RISK: Route-Specific Risk Oral	CANCER RISK: Route-Specific Risk Dermal	CANCER RISK: Route-Specific Risk Inhalation (trench air)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	NON-CANCER HAZARD: Route-Specific Hazard Dermal	NON-CANCER HAZARD: Route-Specific Hazard Inhalation (trench air)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Metals															
Barium	2.6E-01		1.0E-06			-	-	-	-	-	6.8E-05	5.8E-04		6.5E-04	<1%
Iron	2.8E+01		1.0E-06			-	-	-	-	-	7.3E-04	4.4E-04	-	1.2E-03	<1%
Lead	1.2E-03		1.0E-07			-	-	-	-	-	-	-	-	-	-
VOCs															
1,2,4-Trimethylbenzene	1.1E-01	7.5E+00	2.6E-04	8.5E-01	V	-	-	-	-	-	-	-	1.7E-01	1.7E-01	2.0%
1,3,5-Trimethylbenzene	1.2E-01	7.6E+00	1.8E-04	9.2E-01	V	-	-	-	-	-	2.2E-05	2.4E-03	1.3E+00	1.3E+00	15.0%
4-Isopropyltoluene (p-cymene)	3.3E-02	7.2E+00	5.0E-04	2.4E-01	V	-	-	-	-	-	-	-	-	-	-
Benzene	1.3E+00	9.3E+00	2.3E-05	1.2E+01	V	1.9E-08	2.7E-07	2.0E-05	2.0E-05	73%	2.4E-03	3.4E-02	2.2E+00	2.3E+00	25.9%
Ethylbenzene	1.8E-01	8.0E+00	8.8E-05	1.4E+00	V	5.1E-10	2.7E-08	7.4E-07	7.7E-07	3%	6.5E-05	3.4E-03	2.3E-03	5.8E-03	<1%
n-Propylbenzene	8.0E-02	7.6E+00	2.8E-04	6.1E-01	V	-	-	-	-	-	1.5E-05	2.5E-03	8.7E-03	1.1E-02	<1%
Toluene	1.4E+00	8.6E+00	5.2E-05	1.2E+01	V	-	-	-	-	-	3.2E-05	1.0E-03	3.5E-02	3.6E-02	<1%
Xylenes	1.2E+00	8.0E+00	9.5E-05	9.5E+00	V	-	-	-	-	-	5.4E-05	3.1E-03	3.4E-01	3.4E-01	3.9%
SVOCs															
1-Methylnaphthalene	3.5E-02	6.3E+00	3.3E-04	2.2E-01	V	2.6E-10	5.2E-08	-	5.2E-08	<1%	9.1E-06	1.8E-03	-	1.8E-03	<1%
2-Methylnaphthalene	2.5E-02	6.3E+00	3.2E-04	1.6E-01	V	-	-	-	-	-	1.1E-04	2.2E-02	-	2.2E-02	<1%
PAHs															
Naphthalene	1.5E-01	6.6E+00	9.7E-05	9.6E-01	V	-	-	6.6E-06	6.6E-06	24%	1.3E-04	7.7E-03	4.6E+00	4.6E+00	52.3%
Miscellaneous															
Sulfolane	8.3E-01		2.0E-07			-	-	-	-	-	1.5E-03	1.8E-04	-	1.7E-03	<1%
GRO	2.1E+01		NA			-	-	-	-	-	-	-	-	-	-
DRO	1.5E+00		NA			-	-	-	-	-	-	-	-	-	-
RRO	2.8E-01		NA			-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard						2E-08	3E-07	3E-05	3E-05		5E-03	8E-02	9E+00	9E+00	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:
[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

Table E-3b

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Groundwater in a Trench - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Parameters (see Table 3-12a for definitions):

Exposure Duration SUBCHRONIC

CST_ATc	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_FIgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Equations:

ELCRo = (EPCgw × FIgw × IRinc_gw × EFgw × ED × CSFo) / (BW × ATc)

ELCRd = (EPCgw × DA × SAgw × EvFgw × EFgw × ED × CSFd) / (BW × ATc)

ELCRta (VOCs) = ([EPCgw × VF] × EFgw × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCgw × FIgw × IRinc_gw × EFgw × ED) / (BW × ATnc × RfDo)

HQd = (EPCgw × DA ×SAgw ×EvFgw × EFgw × ED) / (BW × ATnc × RfDa)

HQta (VOCs) = ([EPCgw × VF] × ET × EFgw × ED) / (24 × ATnc × RfC)

Table E-4
Chronic Risk and Hazard Estimates for the Onsite Adult Visitor Exposed to Indoor Air - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (ug/L) [b]	EPCsg (mg/m^3) [a]	AF [a]	EPCia (mg/m^3) [a]		CANCER RISK: Route-Specific Risk Inhalation (indoor air)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Inhalation (indoor air)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Metals											
Barium	2.6E+02							-			-
Iron	2.8E+04							-			-
Lead	1.2E+00							-			-
VOCs											
1,2,4-Trimethylbenzene	1.1E+02	7.3E+00	1.1E-05	8.2E-05	V	-		-	3.2E-05	3.2E-05	14.1%
1,3,5-Trimethylbenzene	1.2E+02	7.5E+00	1.3E-05	9.5E-05	V	-		-	-		-
4-Isopropyltoluene (p-cymene)	3.3E+01				V			-			-
Benzene	1.3E+03	1.2E+02	1.0E-05	1.2E-03	V	1.1E-08	1.1E-08	80%	1.1E-04	1.1E-04	49.7%
Ethylbenzene	1.8E+02	1.8E+01	7.5E-06	1.4E-04	V	4.0E-10	4.0E-10	3%	3.7E-07	3.7E-07	<1%
n-Propylbenzene	8.0E+01	9.4E+00	6.5E-06	6.0E-05	V	-		-	1.7E-07	1.7E-07	<1%
Toluene	1.4E+03	1.4E+02	8.7E-06	1.2E-03	V	-		-	6.5E-07	6.5E-07	<1%
Xylenes	1.2E+03	1.1E+02	8.4E-06	9.5E-04	V	-		-	2.6E-05	2.6E-05	11.5%
SVOCs											
1-Methylnaphthalene	3.5E+01	1.1E-01	1.1E-04	1.2E-05	V	-		-	-		-
2-Methylnaphthalene	2.5E+01	7.9E-02	1.1E-04	8.8E-06	V	-		-	-		-
PAHs											
Naphthalene	1.5E+02	6.3E-01	9.4E-05	6.0E-05	V	2.4E-09	2.4E-09	17%	5.5E-05	5.5E-05	24.1%
Miscellaneous											
Sulfolane	8.3E+02							-			-
GRO	2.1E+04							-			-
DRO	1.5E+03							-			-
RRO	2.8E+02							-			-
Total Risk or Hazard						1E-08	1E-08		2E-04	2E-04	

Abbreviations:

-:	Not applicable	ug/L:	Microgram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCgw:	Exposure point concentration in groundwater (ug/L)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	SVOCs:	Semi-volatile organic compounds
EPCsg:	Exposure point concentration in soil gas (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
AF:	Attenuation factor (unitless)		

Table E-4
Chronic Risk and Hazard Estimates for the Onsite Adult Visitor Exposed to Indoor Air - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Notes:

[a] Modeled from groundwater data using Johnson & Ettinger Soil Gas Model (USEPA, 2004). A commercial air exchange rate of 1 per hour was used. Results presented in Appendix C.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

VIS_ATC	25550
VIS_ATnc	10950
VIS_ED	30
VIS_EF	12
VIS_ET	2

Exposure Duration CHRONIC

Equations:

ELCRia (VOCs) = ([EPCsg × AF] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQia (VOCs) = ([EPCsg × AF] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-5a
Chronic Risk and Hazard Estimates for the Offsite Adult Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals														
Arsenic	7.6E+00	1.3E+09	5.8E-09				3.9E-09	3.9E-09	9%			1.4E-04	1.4E-04	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08				-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05				-		-			-		-
Lead									-					-
Nickel	2.0E+01	1.3E+09	1.5E-08				6.3E-10	6.3E-10	1%			6.3E-05	6.3E-05	6.0%
VOCs														
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06	V			-		-			-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06	V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05	V			1.6E-08	1.6E-08	38%			1.6E-04	1.6E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05	V			-		-			1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05	V			1.4E-08	1.4E-08	33%			1.3E-05	1.3E-05	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05	V			1.9E-09	1.9E-09	4%			9.5E-06	9.5E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04	V			-		-			6.9E-05	6.9E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05	V			-		-			1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04	V			-		-			4.4E-04	4.4E-04	41.7%
SVOCs														
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06	V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06	V			-		-			-		-
PAHs														
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11				*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11				*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11				*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11				*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11				*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11				*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11				*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06	V			6.4E-09	6.4E-09	15%			1.5E-04	1.5E-04	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11				4.2E-12	4.2E-12	<1%			-		-
Miscellaneous														
Sulfolane	3.8E-02	1.3E+09	2.9E-11				-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09				-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07				-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06				-		-			-		-
Total Risk or Hazard					0E+00	0E+00	4E-08	4E-08		0E+00	0E+00	1E-03	1E-03	
Total Risk or Hazard Excluding Arsenic					0E+00	0E+00	4E-08	4E-08		0E+00	0E+00	9E-04	9E-04	

Table E-5a

Chronic Risk and Hazard Estimates for the Offsite Adult Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

		Exposure Duration	CHRONIC
ADUR_ATc	25550	ADUR_ET	12
ADUR_ATnc	10950	ADUR_FI	–
ADUR_AF	–	ADUR_IRs	–
ADUR_BW	70	ADUR_PEF	1316000000
ADUR_ED	30	ADUR_SA	–
ADUR_EF	270		

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-5b
Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	4.7E+00			4.7E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		5E+00	0E+00	0E+00	5E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$$

$$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$$

Table E-5c
Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK: Route-Specific Risk Ingestion (fruit)	CANCER RISK: Route-Specific Risk Ingestion (vegetables)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.7E-01	1.0E+00	1.7E-01	-	-		-	1.2E-01	1.9E-01	3.0E-01	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		1E-01	2E-01	3.0E-01	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

		Exposure Duration	CHRONIC
ADUR_ATC	25550	ADUR_IRPfr	259000
ADUR_ATnc	10950	ADUR_IRPvg	413000
ADUR_ED	30	ADUR_FIp	0.25
ADUR_EF	270		
ADUR_BW	70		

Equations:

$ELCRp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED \times CSF) / (1{,}000{,}000 \times BW \times ATC)$

$HIp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfD)$

Table E-6a
Chronic Risk and Hazard Estimates for the Offsite Child Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK: Route-Specific Risk: Oral [c]	CANCER RISK: Route-Specific Risk: Dermal [c]	CANCER RISK: Route-Specific Risk: Inhalation (ambient)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard: Oral [c]	NON-CANCER HAZARD: Route-Specific Hazard: Dermal [c]	NON-CANCER HAZARD: Route-Specific Hazard: Inhalation (ambient)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Metals														
Arsenic	7.6E+00	1.3E+09	5.8E-09				7.9E-10	7.9E-10	9%			1.4E-04	1.4E-04	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08				-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05				-		-			-		-
Lead									-					-
Nickel	2.0E+01	1.3E+09	1.5E-08				1.3E-10	1.3E-10	1%			6.3E-05	6.3E-05	6.0%
VOCs														
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06	V			-		-			-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06	V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05	V			3.3E-09	3.3E-09	38%			1.6E-04	1.6E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05	V			-		-			1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05	V			2.8E-09	2.8E-09	33%			1.3E-05	1.3E-05	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05	V			3.8E-10	3.8E-10	4%			9.5E-06	9.5E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04	V			-		-			6.9E-05	6.9E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05	V			-		-			1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04	V			-		-			4.4E-04	4.4E-04	41.7%
SVOCs														
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06	V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06	V			-		-			-		-
PAHs														
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11				*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11				*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11				*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11				*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11				*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11				*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11				*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06	V			1.3E-09	1.3E-09	15%			1.5E-04	1.5E-04	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11				8.4E-13	8.4E-13	<1%			-		-
Miscellaneous														
Sulfolane	3.8E-02	1.3E+09	2.9E-11				-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09				-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07				-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06				-		-			-		-
Total Risk or Hazard					0E+00	0E+00	9E-09	9E-09		0E+00	0E+00	1E-03	1E-03	
Total Risk or Hazard Excluding Arsenic					0E+00	0E+00	8E-09	8E-09		0E+00	0E+00	9E-04	9E-04	

Table E-6a

Chronic Risk and Hazard Estimates for the Offsite Child Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	mg/m$^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m³/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

		Exposure Duration	CHRONIC
CHR_ATc	25550	CHR_ET	12
CHR_ATnc	2190	CHR_FI	–
CHR_AF	–	CHR_IRs	–
CHR_BW	15	CHR_PEF	1316000000
CHR_ED	6	CHR_SA	–
CHR_EF	270		

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-6b
Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	1.1E+01			1.1E+01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		1.1E+01	0E+00	0E+00	1.1E+01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-6c
Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK			Percent Total ELCR	NON-CANCER HAZARD			Percent Total HI
				Route-Specific Risk		Calculated Risk		Route-Specific Hazard		Calculated Hazard	
				Ingestion (fruit)	Ingestion (vegetables)			Ingestion (fruit)	Ingestion (vegetables)		
Miscellaneous											
Sulfolane	1.7E-01	1.0E+00	1.7E-01	-	-		-	4.7E-01	4.2E-01	8.9E-01	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		5E-01	4E-01	9E-01	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_IRPfr	223500
CHR_ATnc	2190	CHR_IRPvg	201000
CHR_ED	6	CHR_FIp	0.25
CHR_EF	270		
CHR_BW	15		

Exposure Duration CHRONIC

Equations:

$ELCRp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED \times CSF) / (1{,}000{,}000 \times BW \times ATC)$

$HIp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfD)$

Table E-7a
Subchronic Risk and Hazard Estimates for the Offsite Infant Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral [c]	Dermal [c]	Inhalation (ambient)			Oral [c]	Dermal [c]	Inhalation (ambient)		
Metals														
Arsenic	7.6E+00	1.3E+09	5.8E-09				1.3E-10	1.3E-10	9%			1.4E-04	1.4E-04	21.3%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08				-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05				-		-			-		-
Lead									-					-
Nickel	2.0E+01	1.3E+09	1.5E-08				2.1E-11	2.1E-11	1%			6.3E-05	6.3E-05	9.4%
VOCs														
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06	V			-		-			1.2E-04	1.2E-04	17.3%
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06	V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05	V			5.5E-10	5.5E-10	38%			6.2E-05	6.2E-05	9.2%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05	V			-		-			1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05	V			4.7E-10	4.7E-10	33%			1.5E-06	1.5E-06	<1%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05	V			6.4E-11	6.4E-11	4%			3.2E-06	3.2E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04	V			-		-			2.4E-05	2.4E-05	3.6%
Toluene	8.2E-02	4.6E+03	1.8E-05	V			-		-			1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04	V			-		-			1.1E-04	1.1E-04	16.3%
SVOCs														
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06	V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06	V			-		-			-		-
PAHs														
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11				*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11				*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11				*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11				*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11				*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11				*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11				*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06	V			2.1E-10	2.1E-10	15%			1.5E-04	1.5E-04	21.8%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11				1.4E-13	1.4E-13	<1%			-		-
Miscellaneous														
Sulfolane	3.8E-02	1.3E+09	2.9E-11				-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09				-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07				-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06				-		-			-		-
Total Risk or Hazard					0E+00	0E+00	1E-09	1E-09		0E+00	0E+00	7E-04	7E-04	
Total Risk or Hazard Excluding Arsenic					0E+00	0E+00	1E-09	1E-09		0E+00	0E+00	5E-04	5E-04	

Table E-7a

Subchronic Risk and Hazard Estimates for the Offsite Infant Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	mg/m$^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m³/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

INF_ATc	25550	Exposure Duration	SUBCHRONIC
INF_ATnc	365	INF_ET	12
INF_AF	–	INF_FI	–
INF_BW	6.75	INF_IRs	–
INF_ED	1	INF_PEF	1316000000
INF_EF	270	INF_SA	–

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-7b
Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	2.5E+00			2.5E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E+00	0E+00	0E+00	3E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table E-7c
Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK: Route-Specific Risk Ingestion (fruit)	CANCER RISK: Route-Specific Risk Ingestion (vegetables)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.7E-01	1.0E+00	1.7E-01	-	-		-	7.2E-02	5.1E-02	1.2E-01	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		7E-02	5E-02	1E-01	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_IRPfr	155250
INF_ATnc	365	INF_IRPvg	109350
INF_ED	1	INF_FIp	0.25
INF_EF	270		
INF_BW	6.75		

Exposure Duration SUBCHRONIC

Equations:

$$ELCRp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED \times CSF) / (1{,}000{,}000 \times BW \times ATC)$$

$$HIp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfD)$$

Table E-8
Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] (L/cm²/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK: Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	3.3E+00			3.3E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E+00	0E+00	0E+00	3E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm²/event)	L/cm²/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m³)	mg/m³:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m³)	VF:	Volatilization factor (m³/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m³)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-9a

Chronic Risk and Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral [c]	Dermal [c]	Inhalation (ambient)			Oral [c]	Dermal [c]	Inhalation (ambient)		
Metals														
Arsenic	7.6E+00	1.3E+09	5.8E-09				2.0E-09	2.0E-09	9%			8.8E-05	8.8E-05	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08				-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05				-		-			-		-
Lead									-					-
Nickel	2.0E+01	1.3E+09	1.5E-08				3.3E-10	3.3E-10	1%			3.9E-05	3.9E-05	6.0%
VOCs														
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06	V			-		-			-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06	V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05	V			8.5E-09	8.5E-09	38%			1.0E-04	1.0E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05	V			-		-			1.0E-06	1.0E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05	V			7.3E-09	7.3E-09	33%			8.2E-06	8.2E-06	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05	V			9.8E-10	9.8E-10	4%			5.8E-06	5.8E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04	V			-		-			4.2E-05	4.2E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05	V			-		-			8.1E-07	8.1E-07	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04	V			-		-			2.7E-04	2.7E-04	41.7%
SVOCs														
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06	V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06	V			-		-			-		-
PAHs														
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11				*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11				*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11				*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11				*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11				*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11				*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11				*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06	V			3.3E-09	3.3E-09	15%			9.0E-05	9.0E-05	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11				2.2E-12	2.2E-12	<1%			-		-
Miscellaneous														
Sulfolane	3.8E-02	1.3E+09	2.9E-11				-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09				-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07				-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06				-		-			-		-
Total Risk or Hazard					0E+00	0E+00	2E-08	2E-08		0E+00	0E+00	6E-04	6E-04	
Total Risk or Hazard Excluding Arsenic					0E+00	0E+00	2E-08	2E-08		0E+00	0E+00	6E-04	6E-04	

Table E-9a

Chronic Risk and Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	mg/m$^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m³/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

		Exposure Duration	CHRONIC
Clo_ATc	25550	Clo_ET	8
Clo_ATnc	9125	Clo_FI	1
Clo_BW	70	Clo_IRs	100
Clo_ED	25	Clo_PEF	1316000000
Clo_EF	250		

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-9b
Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	3.3E+00			3.3E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E+00	0E+00	0E+00	3E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CIo_ATC	25550	CIo_ETgwi	–
CIo_ATnc	9125	CIo_EvFgw	–
CIo_BW	70	CIo_FIgw	1
CIo_ED	25	CIo_IRgw	2
CIo_EFgw	250	CIo_Sagw	–
CIo_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table E-10
Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral	Dermal [c]	Inhalation (domestic use) [c]			Oral	Dermal [c]	Inhalation (domestic use) [c]		
Miscellaneous														
Sulfolane	1.7E-01		2.0E-07		-			-	-	3.1E-04			3.1E-04	100.0%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		3E-04	0E+00	0E+00	3E-04	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	mg/m^3:	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:
[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CST_ATC	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_FIgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Exposure Duration SUBCHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-11a
Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	1.6E+00			1.6E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E+00	0E+00	0E+00	2E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EgwF × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table E-11b
Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK: Route-Specific Risk Ingestion (fruit)	CANCER RISK: Route-Specific Risk Ingestion (vegetables)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	5.9E-02	1.0E+00	5.9E-02	-	-		-	4.0E-02	6.4E-02	1.0E-01	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		4E-02	6E-02	1E-01	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

		Exposure Duration	CHRONIC
ADUR_ATC	25550	ADUR_IRPfr	259000
ADUR_ATnc	10950	ADUR_IRPvg	413000
ADUR_ED	30	ADUR_FIp	0.25
ADUR_EF	270		
ADUR_BW	70		

Equations:

$ELCRp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED \times CSF) / (1{,}000{,}000 \times BW \times ATC)$

$HIp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfD)$

Table E-12a
Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	3.8E+00			3.8E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		4E+00	0E+00	0E+00	4E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-12b
Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK			Percent Total ELCR	NON-CANCER HAZARD			Percent Total HI
				Route-Specific Risk		Calculated Risk		Route-Specific Hazard		Calculated Hazard	
				Ingestion (fruit)	Ingestion (vegetables)			Ingestion (fruit)	Ingestion (vegetables)		
Miscellaneous											
Sulfolane	5.9E-02	1.0E+00	5.9E-02	-	-		-	1.6E-01	1.5E-01	3.1E-01	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		2E-01	1E-01	3E-01	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_IRPfr	223500
CHR_ATnc	2190	CHR_IRPvg	201000
CHR_ED	6	CHR_FIp	0.25
CHR_EF	270		
CHR_BW	15		

Exposure Duration CHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table E-13a
Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	8.9E-01			8.9E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		9E-01	0E+00	0E+00	9E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table E-13b
Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK: Route-Specific Risk Ingestion (fruit)	CANCER RISK: Route-Specific Risk Ingestion (vegetables)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	5.9E-02	1.0E+00	5.9E-02	-	-		-	2.5E-02	1.8E-02	4.3E-02	100.0%
Total Risk or Hazard				0E+00	0E+00	0E+00		3E-02	2E-02	4E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_IRPfr	155250
INF_ATnc	365	INF_IRPvg	109350
INF_ED	1	INF_FIp	0.25
INF_EF	270		
INF_BW	6.75		

Exposure Duration SUBCHRONIC

Equations:

$$ELCRp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED \times CSF) / (1{,}000{,}000 \times BW \times ATC)$$

$$HIp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfD)$$

Table E-14
Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] (L/cm²/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK: Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	1.2E+00			1.2E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		1E+00	0E+00	0E+00	1E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm²/event)	L/cm²/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m³)	mg/m³:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m³)	VF:	Volatilization factor (m³/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m³)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-15
Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	1.2E+00			1.2E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		1E+00	0E+00	0E+00	1E+00	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CIo_ATC	25550	CIo_ETgwi	–
CIo_ATnc	9125	CIo_EvFgw	–
CIo_BW	70	CIo_FIgw	1
CIo_ED	25	CIo_IRgw	2
CIo_EFgw	250	CIo_Sagw	–
CIo_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table E-16
Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral	Dermal [c]	Inhalation (trench air) [c]			Oral	Dermal [c]	Inhalation (trench air) [c]		
Miscellaneous														
Sulfolane	5.9E-02		2.0E-07		-			-	-	1.1E-04			1.1E-04	100%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		1E-04	0E+00	0E+00	1E-04	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:
[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CST_ATC	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_FIgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Exposure Duration SUBCHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-17a
Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	2.8E-01			2.8E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E-01	0E+00	0E+00	3E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-17b
Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK: Route-Specific Risk Ingestion (fruit)	CANCER RISK: Route-Specific Risk Ingestion (vegetables)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.0E-02	1.0E+00	1.0E-02	-	-		-	7.0E-03	1.1E-02	1.8E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		7E-03	1E-02	2E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

		Exposure Duration	CHRONIC
ADUR_ATC	25550	ADUR_IRPfr	259000
ADUR_ATnc	10950	ADUR_IRPvg	413000
ADUR_ED	30	ADUR_FIp	0.25
ADUR_EF	270		
ADUR_BW	70		

Equations:

$ELCRp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED \times CSF) / (1{,}000{,}000 \times BW \times ATC)$

$HIp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfD)$

Table E-18a
Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	6.5E-01			6.5E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		7E-01	0E+00	0E+00	7E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-18b
Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK: Route-Specific Risk Ingestion (fruit)	CANCER RISK: Route-Specific Risk Ingestion (vegetables)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.0E-02	1.0E+00	1.0E-02	-	-		-	2.8E-02	2.5E-02	5.3E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		3E-02	3E-02	5E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	Exposure Duration	CHRONIC
CHR_ATnc	2190	CHR_IRPfr	223500
CHR_ED	6	CHR_IRPvg	201000
CHR_EF	270	CHR_FIp	0.25
CHR_BW	15		

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × FIp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table E-19a
Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	1.5E-01			1.5E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-01	0E+00	0E+00	2E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table E-19b
Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK: Route-Specific Risk Ingestion (fruit)	CANCER RISK: Route-Specific Risk Ingestion (vegetables)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD: Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.0E-02	1.0E+00	1.0E-02	-	-		-	4.3E-03	3.1E-03	7.4E-03	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		4E-03	3E-03	7E-03	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_IRPfr	155250
INF_ATnc	365	INF_IRPvg	109350
INF_ED	1	INF_FIp	0.25
INF_EF	270		
INF_BW	6.75		

Exposure Duration SUBCHRONIC

Equations:

$$ELCRp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED \times CSF) / (1{,}000{,}000 \times BW \times ATC)$$

$$HIp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times FIp \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfD)$$

Table E-20
Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] (L/cm²/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK: Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	2.0E-01			2.0E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-01	0E+00	0E+00	2E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm²/event)	L/cm²/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m³)	mg/m³:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m³)	VF:	Volatilization factor (m³/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m³)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-21
Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	2.0E-01			2.0E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-01	0E+00	0E+00	2E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CIo_ATC	25550	CIo_ETgwi	–
CIo_ATnc	9125	CIo_EvFgw	–
CIo_BW	70	CIo_FIgw	1
CIo_ED	25	CIo_IRgw	2
CIo_EFgw	250	CIo_Sagw	–
CIo_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table E-22
Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - PPRTV Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral	Dermal [c]	Inhalation (trench air) [c]			Oral	Dermal [c]	Inhalation (trench air) [c]		
Miscellaneous														
Sulfolane	1.0E-02		2.0E-07		-			-	-	1.8E-05			1.8E-05	100%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		2E-05	0E+00	0E+00	2E-05	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:
[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CST_ATC	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_FIgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Exposure Duration SUBCHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-23

Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Indoor Worker Exposed to Indoor Air - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (ug/L) [b]	EPCsg (mg/m^3) [a]	AF [a]	EPCia (mg/m^3) [a]		CANCER RISK: Route-Specific Risk Inhalation (indoor air)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Inhalation (indoor air)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Metals											
Barium	2.6E+02							-			-
Iron	2.8E+04							-			-
Lead	1.2E+00							-			-
VOCs											
1,2,4-Trimethylbenzene	1.1E+02	7.3E+00	1.1E-05	8.2E-05	V	-		-	2.7E-03	2.7E-03	14.1%
1,3,5-Trimethylbenzene	1.2E+02	7.5E+00	1.3E-05	9.5E-05	V	-		-	-		-
4-Isopropyltoluene (p-cymene)	3.3E+01				V			-			-
Benzene	1.3E+03	1.2E+02	1.0E-05	1.2E-03	V	7.9E-07	7.9E-07	80%	9.4E-03	9.4E-03	49.7%
Ethylbenzene	1.8E+02	1.8E+01	7.5E-06	1.4E-04	V	2.8E-08	2.8E-08	3%	3.1E-05	3.1E-05	<1%
n-Propylbenzene	8.0E+01	9.4E+00	6.5E-06	6.0E-05	V	-		-	1.4E-05	1.4E-05	<1%
Toluene	1.4E+03	1.4E+02	8.7E-06	1.2E-03	V	-		-	5.4E-05	5.4E-05	<1%
Xylenes	1.2E+03	1.1E+02	8.4E-06	9.5E-04	V	-		-	2.2E-03	2.2E-03	11.5%
SVOCs											
1-Methylnaphthalene	3.5E+01	1.1E-01	1.1E-04	1.2E-05	V	-		-	-		-
2-Methylnaphthalene	2.5E+01	7.9E-02	1.1E-04	8.8E-06	V	-		-	-		-
PAHs											
Naphthalene	1.5E+02	6.3E-01	9.4E-05	6.0E-05	V	1.7E-07	1.7E-07	17%	4.6E-03	4.6E-03	24.1%
Miscellaneous											
Sulfolane	8.3E+02							-			-
GRO	2.1E+04							-			-
DRO	1.5E+03							-			-
RRO	2.8E+02							-			-
Total Risk or Hazard						1E-06	1E-06		2E-02	2E-02	

Abbreviations:

-:	Not applicable	ug/L:	Microgram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCgw:	Exposure point concentration in groundwater (ug/L)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	SVOCs:	Semi-volatile organic compounds
EPCsg:	Exposure point concentration in soil gas (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
AF:	Attenuation factor (unitless)		

Table E-23

Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Indoor Worker Exposed to Indoor Air - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Notes:

[a] Modeled from groundwater data using Johnson & Ettinger Soil Gas Model (USEPA, 2004). A commercial air exchange rate of 1 per hour was used. Results presented in Appendix C.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CI_ATC	25550
CI_ATnc	9125
CI_ED	25
CI_EF	250
CI_ET	8

Exposure Duration CHRONIC

Equations:

ELCRia (VOCs) = ([EPCsg × AF] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQia (VOCs) = ([EPCsg × AF] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-24

Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)		EPCia (mg/m^3) [b]	CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.6E+00	1.3E+09	5.8E-09			4.0E-06	5.3E-07	2.0E-09	4.5E-06	97%	2.5E-02	3.3E-03	8.8E-05	2.8E-02	52.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08			-	-	-	-	-	1.3E-05	-	-	1.3E-05	<1%
Iron	1.7E+04	1.3E+09	1.3E-05			-	-	-	-	-	2.4E-02	-	-	2.4E-02	44.3%
Lead							-			-		-			-
Nickel	2.0E+01	1.3E+09	1.5E-08			-	-	3.3E-10	3.3E-10	<1%	9.9E-04	-	3.9E-05	1.0E-03	1.9%
VOCs															
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V	-	-	-	-	-	2.2E-06	-	-	2.2E-06	<1%
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V	-	-	-	-	-	-	-	-	-	-
Benzene	5.1E-02	3.8E+03	1.3E-05		V	9.8E-10	-	8.5E-09	9.5E-09	<1%	1.2E-05	-	1.0E-04	1.1E-04	<1%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V	-	-	-	-	-	-	-	1.0E-06	1.0E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V	8.4E-10	-	7.3E-09	8.1E-09	<1%	2.1E-06	-	8.2E-06	1.0E-05	<1%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V	1.6E-10	-	9.8E-10	1.1E-09	<1%	9.8E-07	-	5.8E-06	6.8E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V	-	-	-	-	-	1.9E-06	-	4.2E-05	4.4E-05	<1%
Toluene	8.2E-02	4.6E+03	1.8E-05		V	-	-	-	-	-	1.0E-06	-	8.1E-07	1.8E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V	-	-	-	-	-	3.6E-06	-	2.7E-04	2.7E-04	<1%
SVOCs															
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V	2.5E-09	-	-	2.5E-09	<1%	3.4E-06	-	-	3.4E-06	<1%
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V	-	-	-	-	-	6.7E-05	-	-	6.7E-05	<1%
PAHs															
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11			*	*	*	*	-	-	-	-	-	-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11			*	*	*	*	-	-	-	-	-	-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11			*	*	*	*	-	-	-	-	-	-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11			*	*	*	*	-	-	-	-	-	-
Chrysene	6.6E-02	1.3E+09	5.0E-11			*	*	*	*	-	-	-	-	-	-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11			*	*	*	*	-	-	-	-	-	-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11			*	*	*	*	-	-	-	-	-	-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V	-	-	3.3E-09	3.3E-09	<1%	2.9E-06	1.7E-06	9.0E-05	9.5E-05	<1%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11			8.1E-08	4.7E-08	2.2E-12	1.3E-07	3%	-	-	-	-	-
Miscellaneous															
Sulfolane	3.8E-02	1.3E+09	2.9E-11			-	-	-	-	-	3.7E-06	-	-	3.7E-06	<1%
GRO	5.4E+00	1.3E+09	4.1E-09			-	-	-	-	-	-	-	-	-	-
DRO	2.1E+02	1.3E+09	1.6E-07			-	-	-	-	-	-	-	-	-	-
RRO	1.9E+03	1.3E+09	1.4E-06			-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard						4E-06	6E-07	2E-08	5E-06		5E-02	3E-03	6E-04	5E-02	
Total Risk or Hazard Excluding Arsenic						9E-08	5E-08	2E-08	2E-07		2E-02	2E-06	6E-04	3E-02	

Table E-24

Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

		Exposure Duration	CHRONIC
Clo_ATc	25550	Clo_ET	8
Clo_ATnc	9125	Clo_EvFs	1
Clo_AF	0.2	Clo_FI	1
Clo_BW	70	Clo_IRs	100
Clo_ED	25	Clo_PEF	1316000000
Clo_EF	250	Clo_SA	2230

Equations:

ELCRo = (EPCs × FI × IRs × EF × ED × CSFo) / (1,000,000 × BW × ATc)

ELCRd = ([EPCs × AF × ABSd] × SA × EvFs × EF × ED × CSFd) / (1,000,000 × BW × ATc)

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCs × FI × IRs × EF × ED) / (1,000,000 × BW × ATnc × RfDo)

HQd = ([EPCs × AF ×ABSd]) × SA ×EvFs × EF × ED) / (1,000,000 × BW × ATnc × RfDa)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-25a

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Subsurface Soil (0 to 15 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.3E+00	1.0E+06	7.3E-06			2.5E-07	1.5E-08	6.4E-09	2.7E-07	94%	2.4E-03	1.4E-04	7.0E-03	9.5E-03	16.5%
Chromium, Total	1.7E+01	1.0E+06	1.7E-05			-	-	-	-	-	1.8E-05	-	-	1.8E-05	<1%
Iron	1.5E+04	1.0E+06	1.5E-02			-	-	-	-	-	3.5E-02	-	-	3.5E-02	60.5%
Nickel	1.9E+01	1.0E+06	1.9E-05			-	-	1.0E-09	1.0E-09	<1%	1.5E-03	-	3.0E-03	4.5E-03	7.9%
VOCs															
1,2,4-Trimethylbenzene	2.2E+01	8.5E+03	2.6E-03		V	-	-	-	-	-	-	-	5.3E-04	5.3E-04	<1%
1,3,5-Trimethylbenzene	8.3E+00	7.1E+03	1.2E-03		V	-	-	-	-	-	1.3E-04	-	1.7E-03	1.8E-03	3.1%
4-Isopropyltoluene (p-cymene)	2.0E+00	9.4E+03	2.2E-04		V	-	-	-	-	-	-	-	-	-	-
Benzene	3.1E+00	3.8E+03	8.2E-04		V	4.0E-09	-	1.3E-09	5.3E-09	2%	5.1E-04	-	1.5E-04	6.5E-04	1.1%
Cyclohexane	5.6E+00	1.1E+03	5.0E-03		V	-	-	-	-	-	-	-	1.2E-05	1.2E-05	<1%
Ethylbenzene	8.7E+00	6.1E+03	1.4E-03		V	2.2E-09	-	7.2E-10	2.9E-09	<1%	2.8E-04	-	2.3E-06	2.8E-04	<1%
Isopropylbenzene (cumene)	4.0E+00	6.7E+03	5.9E-04		V	-	-	-	-	-	1.6E-05	-	9.4E-05	1.1E-04	<1%
Methylene chloride	2.9E-01	2.4E+03	1.2E-04		V	5.0E-11	-	1.2E-11	6.2E-11	<1%	7.8E-06	-	5.8E-07	8.4E-06	<1%
n-Butylbenzene	7.6E+00	8.8E+03	8.7E-04		V	-	-	-	-	-	1.2E-04	-	-	1.2E-04	<1%
n-Hexane	2.4E+00	8.9E+02	2.7E-03		V	-	-	-	-	-	1.3E-05	-	1.9E-05	3.2E-05	<1%
n-Propylbenzene	7.2E+00	7.5E+03	9.6E-04		V	-	-	-	-	-	1.2E-04	2.4E-05	1.4E-05	1.5E-04	<1%
sec-Butylbenzene	6.6E+00	8.1E+03	8.1E-04		V	-	-	-	-	-	-	-	-	-	-
Toluene	1.7E+01	4.6E+03	3.8E-03		V	-	-	-	-	-	3.5E-05	-	1.1E-05	4.6E-05	<1%
Xylenes	4.7E+01	6.3E+03	7.5E-03		V	-	-	-	-	-	1.9E-04	-	2.7E-04	4.6E-04	<1%
SVOCs															
1-Methylnaphthalene	4.6E+00	6.3E+04	7.3E-05		V	3.1E-09	-	-	3.1E-09	1%	1.1E-04	-	-	1.1E-04	<1%
2-Methylnaphthalene	8.6E+00	6.2E+04	1.4E-04		V	-	-	-	-	-	3.5E-03	-	-	3.5E-03	6.0%
PAHs															
Benzo (a) anthracene	1.2E-02	1.0E+06	1.2E-08			*	*	*	*	-	-	-	-	-	-
Benzo (a) pyrene	1.2E-02	1.0E+06	1.2E-08			*	*	*	*	-	-	-	-	-	-
Benzo (b) fluoranthene	2.1E-02	1.0E+06	2.1E-08			*	*	*	*	-	-	-	-	-	-
Benzo (k) fluoranthene	1.9E-02	1.0E+06	1.9E-08			*	*	*	*	-	-	-	-	-	-
Chrysene	3.5E-02	1.0E+06	3.5E-08			*	*	*	*	-	-	-	-	-	-
Dibenzo (a,h) anthracene	9.9E-03	1.0E+06	9.9E-09			*	*	*	*	-	-	-	-	-	-
Indeno (1,2,3-cd) pyrene	1.1E-02	1.0E+06	1.1E-08			*	*	*	*	-	-	-	-	-	-
Naphthalene	4.4E+00	5.0E+04	8.8E-05		V	-	-	6.1E-10	6.1E-10	<1%	3.5E-04	9.3E-05	4.2E-04	8.6E-04	1.5%

Table E-25a

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Subsurface Soil (0 to 15 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]	CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Total Benzo(a)pyrene TEQ	2.6E-02	1.0E+06	2.6E-08		4.3E-09	1.1E-09	5.8E-12	5.5E-09	2%	-	-	-	-	-
Miscellaneous														
Sulfolane	4.5E-01	1.0E+06	4.5E-07		-	-	-	-	-	7.3E-06	-	-	7.3E-06	<1%
GRO	8.1E+02	1.0E+06	8.1E-04		-	-	-	-	-	-	-	-	-	-
DRO	2.1E+03	1.0E+06	2.1E-03		-	-	-	-	-	-	-	-	-	-
RRO	8.2E+03	1.0E+06	8.2E-03		-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard					3E-07	2E-08	1E-08	3E-07		4E-02	3E-04	1E-02	6E-02	
Total Risk or Hazard Excluding Arsenic					1E-08	1E-09	4E-09	2E-08		4E-02	1E-04	6E-03	5E-02	

Abbreviations:

-:	Not applicable	$mg/m^{3:}$	Milligram(s) per cubic meter
ELCR:	Excess lifetime cancer risk (unitless)	PAH:	Polycyclic aromatic hydrocarbon
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
mg/kg:	Milligram(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk
m^3/kg:	Cubic meter(s) per kilogram		

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CST_ATc	25550	CST_ET	1
CST_ATnc	365	CST_EvFs	1
CST_AF	0.3	CST_FI	1
CST_BW	70	CST_IRs	330
CST_ED	1	CST_PEF	1.00E+06
CST_EF	125	CST_SA	2230

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCs × FI × IRs × EF × ED × CSFo) / (1,000,000 × BW × ATc)
ELCRd = ([EPCs × AF × ABSd] × SA × EvFs × EF × ED × CSFd) / (1,000,000 × BW × ATc)
ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCs × FI × IRs × EF × ED) / (1,000,000 × BW × ATnc × RfDo)
HQd = ([EPCs × AF ×ABSd]) × SA ×EvFs × EF × ED) / (1,000,000 × BW × ATnc × RfDa)
HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-25b

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Groundwater in a Trench - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCta [a] (mg/m3)		CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (trench air)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (trench air)	Calculated Hazard	Percent Total HI
Metals															
Barium	2.6E-01		1.0E-06			-	-	-	-	-	6.8E-05	5.8E-04		6.5E-04	<1%
Iron	2.8E+01		1.0E-06			-	-	-	-	-	7.3E-04	4.4E-04	-	1.2E-03	<1%
Lead	1.2E-03		1.0E-07			-	-	-	-	-	-	-	-	-	-
VOCs															
1,2,4-Trimethylbenzene	1.1E-01	7.5E+00	2.6E-04	8.5E-01	V	-	-	-	-	-	-	-	1.7E-01	1.7E-01	2.0%
1,3,5-Trimethylbenzene	1.2E-01	7.6E+00	1.8E-04	9.2E-01	V	-	-	-	-	-	2.2E-05	2.4E-03	1.3E+00	1.3E+00	15.0%
4-Isopropyltoluene (p-cymene)	3.3E-02	7.2E+00	5.0E-04	2.4E-01	V	-	-	-	-	-	-	-	-	-	-
Benzene	1.3E+00	9.3E+00	2.3E-05	1.2E+01	V	1.9E-08	2.7E-07	2.0E-05	2.0E-05	73%	2.4E-03	3.4E-02	2.2E+00	2.3E+00	25.9%
Ethylbenzene	1.8E-01	8.0E+00	8.8E-05	1.4E+00	V	5.1E-10	2.7E-08	7.4E-07	7.7E-07	3%	6.5E-05	3.4E-03	2.3E-03	5.8E-03	<1%
n-Propylbenzene	8.0E-02	7.6E+00	2.8E-04	6.1E-01	V	-	-	-	-	-	1.5E-05	2.5E-03	8.7E-03	1.1E-02	<1%
Toluene	1.4E+00	8.6E+00	5.2E-05	1.2E+01	V	-	-	-	-	-	3.2E-05	1.0E-03	3.5E-02	3.6E-02	<1%
Xylenes	1.2E+00	8.0E+00	9.5E-05	9.5E+00	V	-	-	-	-	-	5.4E-05	3.1E-03	3.4E-01	3.4E-01	3.9%
SVOCs															
1-Methylnaphthalene	3.5E-02	6.3E+00	3.3E-04	2.2E-01	V	2.6E-10	5.2E-08	-	5.2E-08	<1%	9.1E-06	1.8E-03	-	1.8E-03	<1%
2-Methylnaphthalene	2.5E-02	6.3E+00	3.2E-04	1.6E-01	V	-	-	-	-	-	1.1E-04	2.2E-02	-	2.2E-02	<1%
PAHs															
Naphthalene	1.5E-01	6.6E+00	9.7E-05	9.6E-01	V	-	-	6.6E-06	6.6E-06	24%	1.3E-04	7.7E-03	4.6E+00	4.6E+00	52.3%
Miscellaneous															
Sulfolane	8.3E-01		2.0E-07			-	-	-	-	-	1.5E-04	1.8E-05	-	1.7E-04	<1%
GRO	2.1E+01		NA			-	-	-	-	-	-	-	-	-	-
DRO	1.5E+00		NA			-	-	-	-	-	-	-	-	-	-
RRO	2.8E-01		NA			-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard						2E-08	3E-07	3E-05	3E-05		4E-03	8E-02	9E+00	9E+00	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	mg/m^3:	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m³:	Liter(s) per cubic meter		

Notes:

[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

Table E-25b

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Groundwater in a Trench - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Parameters (see Table 3-12a for definitions):

Exposure Duration SUBCHRONIC

CST_ATc	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_FIgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Equations:

ELCRo = (EPCgw × FIgw × IRinc_gw × EFgw × ED × CSFo) / (BW × ATc)

ELCRd = (EPCgw × DA × SAgw × EvFgw × EFgw × ED × CSFd) / (BW × ATc)

ELCRta (VOCs) = ([EPCgw × VF] × EFgw × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCgw × FIgw × IRinc_gw × EFgw × ED) / (BW × ATnc × RfDo)

HQd = (EPCgw × DA ×SAgw ×EvFgw × EFgw × ED) / (BW × ATnc × RfDa)

HQta (VOCs) = ([EPCgw × VF] × ET × EFgw × ED) / (24 × ATnc × RfC)

Table E-26

Chronic Risk and Hazard Estimates for the Onsite Adult Visitor Exposed to Indoor Air - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (ug/L) [b]	EPCsg (mg/m^3) [a]	AF [a]	EPCia (mg/m^3) [a]		CANCER RISK: Route-Specific Risk Inhalation (indoor air)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Inhalation (indoor air)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Metals											
Barium	2.6E+02							-			-
Iron	2.8E+04							-			-
Lead	1.2E+00							-			-
VOCs											
1,2,4-Trimethylbenzene	1.1E+02	7.3E+00	1.1E-05	8.2E-05	V	-		-	3.2E-05	3.2E-05	14.1%
1,3,5-Trimethylbenzene	1.2E+02	7.5E+00	1.3E-05	9.5E-05	V	-		-	-		-
4-Isopropyltoluene (p-cymene)	3.3E+01				V			-			-
Benzene	1.3E+03	1.2E+02	1.0E-05	1.2E-03	V	1.1E-08	1.1E-08	80%	1.1E-04	1.1E-04	49.7%
Ethylbenzene	1.8E+02	1.8E+01	7.5E-06	1.4E-04	V	4.0E-10	4.0E-10	3%	3.7E-07	3.7E-07	<1%
n-Propylbenzene	8.0E+01	9.4E+00	6.5E-06	6.0E-05	V	-		-	1.7E-07	1.7E-07	<1%
Toluene	1.4E+03	1.4E+02	8.7E-06	1.2E-03	V	-		-	6.5E-07	6.5E-07	<1%
Xylenes	1.2E+03	1.1E+02	8.4E-06	9.5E-04	V	-		-	2.6E-05	2.6E-05	11.5%
SVOCs											
1-Methylnaphthalene	3.5E+01	1.1E-01	1.1E-04	1.2E-05	V	-		-	-		-
2-Methylnaphthalene	2.5E+01	7.9E-02	1.1E-04	8.8E-06	V	-		-	-		-
PAHs											
Naphthalene	1.5E+02	6.3E-01	9.4E-05	6.0E-05	V	2.4E-09	2.4E-09	17%	5.5E-05	5.5E-05	24.1%
Miscellaneous											
Sulfolane	8.3E+02							-			-
GRO	2.1E+04							-			-
DRO	1.5E+03							-			-
RRO	2.8E+02							-			-
Total Risk or Hazard						1E-08	1E-08		2E-04	2E-04	

Abbreviations:

-:	Not applicable	ug/L:	Microgram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCgw:	Exposure point concentration in groundwater (ug/L)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	SVOCs:	Semi-volatile organic compounds
EPCsg:	Exposure point concentration in soil gas (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
AF:	Attenuation factor (unitless)		

Table E-26
Chronic Risk and Hazard Estimates for the Onsite Adult Visitor Exposed to Indoor Air - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Notes:

[a] Modeled from groundwater data using Johnson & Ettinger Soil Gas Model (USEPA, 2004). A commercial air exchange rate of 1 per hour was used. Results presented in Appendix C.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

VIS_ATC	25550
VIS_ATnc	10950
VIS_ED	30
VIS_EF	12
VIS_ET	2

Exposure Duration CHRONIC

Equations:

ELCRia (VOCs) = ([EPCsg × AF] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQia (VOCs) = ([EPCsg × AF] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-27a

Chronic Risk and Hazard Estimates for the Offsite Adult Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.6E+00	1.3E+09	5.8E-09					3.9E-09	3.9E-09	9%			1.4E-04	1.4E-04	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08					-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05					-		-			-		-
Lead										-					-
Nickel	2.0E+01	1.3E+09	1.5E-08					6.3E-10	6.3E-10	1%			6.3E-05	6.3E-05	6.0%
VOCs															
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V			-		-			-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05		V			1.6E-08	1.6E-08	38%			1.6E-04	1.6E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V			-		-			1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V			1.4E-08	1.4E-08	33%			1.3E-05	1.3E-05	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V			1.9E-09	1.9E-09	4%			9.5E-06	9.5E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V			-		-			6.9E-05	6.9E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05		V			-		-			1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V			-		-			4.4E-04	4.4E-04	41.7%
SVOCs															
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V			-		-			-		-
PAHs															
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11					*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11					*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11					*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11					*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11					*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11					*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11					*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V			6.4E-09	6.4E-09	15%			1.5E-04	1.5E-04	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11					4.2E-12	4.2E-12	<1%			-		-
Miscellaneous															
Sulfolane	3.8E-02	1.3E+09	2.9E-11					-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09					-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07					-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06					-		-			-		-
Total Risk or Hazard						0E+00	0E+00	4E-08	4E-08		0E+00	0E+00	1E-03	1E-03	
Total Risk or Hazard Excluding Arsenic						0E+00	0E+00	4E-08	4E-08		0E+00	0E+00	9E-04	9E-04	

Table E-27a

Chronic Risk and Hazard Estimates for the Offsite Adult Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	mg/m$^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m³/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

ADUR_ATc	25550	ADUR_ET	12
ADUR_ATnc	10950	ADUR_FI	–
ADUR_AF	–	ADUR_IRs	–
ADUR_BW	70	ADUR_PEF	1316000000
ADUR_ED	30	ADUR_SA	–
ADUR_EF	270		

Exposure Duration CHRONIC

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-27b

Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	4.7E-01			4.7E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		5E-01	0E+00	0E+00	5E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-27c

Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - Exposure Unit 1 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.7E-01	1.0E+00	1.7E-01	-	-		-	1.2E-02	1.9E-02	3.0E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		1E-02	2E-02	3.0E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_IRPfr	259000
ADUR_ATnc	10950	ADUR_IRPvg	413000
ADUR_ED	30	ADUR_Flp	0.25
ADUR_EF	270		
ADUR_BW	70		

Exposure Duration CHRONIC

Equations:

$ELCRp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times Flp \times EF \times ED \times CSF) / (1{,}000{,}000 \times BW \times ATC)$

$HIp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times Flp \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfD)$

Table E-28a

Chronic Risk and Hazard Estimates for the Offsite Child Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.6E+00	1.3E+09	5.8E-09					7.9E-10	7.9E-10	9%			1.4E-04	1.4E-04	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08					-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05					-		-			-		-
Lead										-					-
Nickel	2.0E+01	1.3E+09	1.5E-08					1.3E-10	1.3E-10	1%			6.3E-05	6.3E-05	6.0%
VOCs															
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V			-		-			-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05		V			3.3E-09	3.3E-09	38%			1.6E-04	1.6E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V			-		-			1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V			2.8E-09	2.8E-09	33%			1.3E-05	1.3E-05	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V			3.8E-10	3.8E-10	4%			9.5E-06	9.5E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V			-		-			6.9E-05	6.9E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05		V			-		-			1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V			-		-			4.4E-04	4.4E-04	41.7%
SVOCs															
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V			-		-			-		-
PAHs															
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11					*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11					*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11					*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11					*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11					*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11					*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11					*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V			1.3E-09	1.3E-09	15%			1.5E-04	1.5E-04	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11					8.4E-13	8.4E-13	<1%			-		-
Miscellaneous															
Sulfolane	3.8E-02	1.3E+09	2.9E-11					-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09					-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07					-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06					-		-			-		-
Total Risk or Hazard						0E+00	0E+00	9E-09	9E-09		0E+00	0E+00	1E-03	1E-03	
Total Risk or Hazard Excluding Arsenic						0E+00	0E+00	8E-09	8E-09		0E+00	0E+00	9E-04	9E-04	

Table E-28a

Chronic Risk and Hazard Estimates for the Offsite Child Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

CHR_ATc	25550	CHR_ET	12
CHR_ATnc	2190	CHR_FI	–
CHR_AF	–	CHR_IRs	–
CHR_BW	15	CHR_PEF	1316000000
CHR_ED	6	CHR_SA	–
CHR_EF	270		

Exposure Duration: CHRONIC

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-28b

Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	1.1E+00			1.1E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		1.1E+00	0E+00	0E+00	1.1E+00	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-28c

Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 1 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.7E-01	1.0E+00	1.7E-01	-	-		-	4.7E-02	4.2E-02	8.9E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		5E-02	4E-02	9E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	Exposure Duration	CHRONIC
CHR_ATnc	2190	CHR_IRPfr	223500
CHR_ED	6	CHR_IRPvg	201000
CHR_EF	270	CHR_Flp	0.25
CHR_BW	15		

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table E-29a

Subchronic Risk and Hazard Estimates for the Offsite Infant Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.6E+00	1.3E+09	5.8E-09					1.3E-10	1.3E-10	9%			1.4E-04	1.4E-04	21.3%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08					-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05					-		-			-		-
Lead										-					-
Nickel	2.0E+01	1.3E+09	1.5E-08					2.1E-11	2.1E-11	1%			6.3E-05	6.3E-05	9.4%
VOCs															
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V			-		-			1.2E-04	1.2E-04	17.3%
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05		V			5.5E-10	5.5E-10	38%			6.2E-05	6.2E-05	9.2%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V			-		-			1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V			4.7E-10	4.7E-10	33%			1.5E-06	1.5E-06	<1%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V			6.4E-11	6.4E-11	4%			3.2E-06	3.2E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V			-		-			2.4E-05	2.4E-05	3.6%
Toluene	8.2E-02	4.6E+03	1.8E-05		V			-		-			1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V			-		-			1.1E-04	1.1E-04	16.3%
SVOCs															
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V			-		-			-		-
PAHs															
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11					*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11					*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11					*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11					*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11					*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11					*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11					*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V			2.1E-10	2.1E-10	15%			1.5E-04	1.5E-04	21.8%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11					1.4E-13	1.4E-13	<1%			-		-
Miscellaneous															
Sulfolane	3.8E-02	1.3E+09	2.9E-11					-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09					-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07					-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06					-		-			-		-
Total Risk or Hazard						0E+00	0E+00	1E-09	1E-09		0E+00	0E+00	7E-04	7E-04	
Total Risk or Hazard Excluding Arsenic						0E+00	0E+00	1E-09	1E-09		0E+00	0E+00	5E-04	5E-04	

Table E-29a

Subchronic Risk and Hazard Estimates for the Offsite Infant Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

INF_ATc	25550	INF_ET	12
INF_ATnc	365	INF_FI	–
INF_AF	–	INF_IRs	–
INF_BW	6.75	INF_PEF	1316000000
INF_ED	1	INF_SA	–
INF_EF	270		

Exposure Duration SUBCHRONIC

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-29b

Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm^2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	2.5E-01			2.5E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E-01	0E+00	0E+00	3E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-29c

Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - Exposure Unit 1 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.7E-01	1.0E+00	1.7E-01	-	-		-	7.2E-03	5.1E-03	1.2E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		7E-03	5E-03	1E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	Exposure Duration	SUBCHRONIC
INF_ATnc	365	INF_IRPfr	155250
INF_ED	1	INF_IRPvg	109350
INF_EF	270	INF_Flp	0.25
INF_BW	6.75		

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table E-30

Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] (L/cm²/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	3.3E-01			3.3E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E-01	0E+00	0E+00	3E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm²/event)	L/cm²/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m³)	mg/m³:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m³)	VF:	Volatilization factor (m³/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m³)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table E-31a

Chronic Risk and Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.6E+00	1.3E+09	5.8E-09					2.0E-09	2.0E-09	9%			8.8E-05	8.8E-05	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08					-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05					-		-			-		-
Lead										-					-
Nickel	2.0E+01	1.3E+09	1.5E-08					3.3E-10	3.3E-10	1%			3.9E-05	3.9E-05	6.0%
VOCs															
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V			-		-			-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05		V			8.5E-09	8.5E-09	38%			1.0E-04	1.0E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V			-		-			1.0E-06	1.0E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V			7.3E-09	7.3E-09	33%			8.2E-06	8.2E-06	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V			9.8E-10	9.8E-10	4%			5.8E-06	5.8E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V			-		-			4.2E-05	4.2E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05		V			-		-			8.1E-07	8.1E-07	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V			-		-			2.7E-04	2.7E-04	41.7%
SVOCs															
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V			-		-			-		-
PAHs															
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11					*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11					*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11					*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11					*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11					*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11					*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11					*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V			3.3E-09	3.3E-09	15%			9.0E-05	9.0E-05	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11					2.2E-12	2.2E-12	<1%			-		-
Miscellaneous															
Sulfolane	3.8E-02	1.3E+09	2.9E-11					-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09					-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07					-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06					-		-			-		-
Total Risk or Hazard						0E+00	0E+00	2E-08	2E-08		0E+00	0E+00	6E-04	6E-04	
Total Risk or Hazard Excluding Arsenic						0E+00	0E+00	2E-08	2E-08		0E+00	0E+00	6E-04	6E-04	

Table E-31a

Chronic Risk and Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12a for definitions):

		Exposure Duration	CHRONIC
CIo_ATc	25550	CIo_ET	8
CIo_ATnc	9125	CIo_FI	1
CIo_BW	70	CIo_IRs	100
CIo_ED	25	CIo_PEF	1316000000
CIo_EF	250		

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table E-31b

Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	3.3E-01			3.3E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E-01	0E+00	0E+00	3E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CIo_ATC	25550	CIo_ETgwi	–
CIo_ATnc	9125	CIo_EvFgw	–
CIo_BW	70	CIo_FIgw	1
CIo_ED	25	CIo_IRgw	2
CIo_EFgw	250	CIo_Sagw	–
CIo_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table E-32

Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - Exposure Unit 1 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral	Dermal [c]	Inhalation (domestic use) [c]			Oral	Dermal [c]	Inhalation (domestic use) [c]		
Miscellaneous														
Sulfolane	1.7E-01		2.0E-07		-			-	-	3.1E-05			3.1E-05	100.0%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		3E-05	0E+00	0E+00	3E-05	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	mg/m^3:	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:

[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

Exposure Duration SUBCHRONIC

CST_ATC	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_Flgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Equations:

$ELCRo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-33a

Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	1.6E-01			1.6E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-01	0E+00	0E+00	2E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EgwF \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-33b

Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - Exposure Unit 2 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	5.9E-02	1.0E+00	5.9E-02	-	-		-	4.0E-03	6.4E-03	1.0E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		4E-03	6E-03	1E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_IRPfr	259000
ADUR_ATnc	10950	ADUR_IRPvg	413000
ADUR_ED	30	ADUR_Flp	0.25
ADUR_EF	270		
ADUR_BW	70		

Exposure Duration CHRONIC

Equations:

$ELCRp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times Flp \times EF \times ED \times CSF) / (1{,}000{,}000 \times BW \times ATC)$

$HIp = ([EPCgw \times BCF] \times [IRfr + IRvg] \times Flp \times EF \times ED) / (1{,}000{,}000 \times BW \times ATnc \times RfD)$

Table E-34a

Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm^2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	3.8E-01			3.8E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		4E-01	0E+00	0E+00	4E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-34b

Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 2 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	5.9E-02	1.0E+00	5.9E-02	-	-		-	1.6E-02	1.5E-02	3.1E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		2E-02	1E-02	3E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_IRPfr	223500
CHR_ATnc	2190	CHR_IRPvg	201000
CHR_ED	6	CHR_Flp	0.25
CHR_EF	270		
CHR_BW	15		

Exposure Duration CHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table E-35a

Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm^2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	8.9E-02			8.9E-02	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		9E-02	0E+00	0E+00	9E-02	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-35b

Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - Exposure Unit 2 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	5.9E-02	1.0E+00	5.9E-02	-	-		-	2.5E-03	1.8E-03	4.3E-03	100.0%
Total Risk or Hazard				0E+00	0E+00	0E+00		3E-03	2E-03	4E-03	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_IRPfr	155250
INF_ATnc	365	INF_IRPvg	109350
INF_ED	1	INF_Flp	0.25
INF_EF	270		
INF_BW	6.75		

Exposure Duration: SUBCHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table E-36

Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] (L/cm²/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	1.2E-01			1.2E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		1E-01	0E+00	0E+00	1E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm²/event)	L/cm²/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m³)	mg/m³:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m³)	VF:	Volatilization factor (m³/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m³)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table E-37

Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	1.2E-01			1.2E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		1E-01	0E+00	0E+00	1E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CIo_ATC	25550	CIo_ETgwi	–
CIo_ATnc	9125	CIo_EvFgw	–
CIo_BW	70	CIo_FIgw	1
CIo_ED	25	CIo_IRgw	2
CIo_EFgw	250	CIo_Sagw	–
CIo_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table E-38

Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - Exposure Unit 2 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK: Route-Specific Risk Oral	Dermal [c]	Inhalation (trench air) [c]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal [c]	Inhalation (trench air) [c]	Calculated Hazard	Percent Total HI
Miscellaneous														
Sulfolane	5.9E-02		2.0E-07		-			-	-	1.1E-05			1.1E-05	100%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		1E-05	0E+00	0E+00	1E-05	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	mg/m^3:	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:

[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

Exposure Duration SUBCHRONIC

CST_ATC	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_Flgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Equations:

$ELCRo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-39a

Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	2.8E-02			2.8E-02	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E-02	0E+00	0E+00	3E-02	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-39b

Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - Exposure Unit 3 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.0E-02	1.0E+00	1.0E-02	-	-		-	7.0E-04	1.1E-03	1.8E-03	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		7E-04	1E-03	2E-03	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

ADUR_ATC	25550	ADUR_IRPfr	259000
ADUR_ATnc	10950	ADUR_IRPvg	413000
ADUR_ED	30	ADUR_Flp	0.25
ADUR_EF	270		
ADUR_BW	70		

Exposure Duration CHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table E-40a

Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	6.5E-02			6.5E-02	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		7E-02	0E+00	0E+00	7E-02	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table E-40b

Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 3 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.0E-02	1.0E+00	1.0E-02	-	-		-	2.8E-03	2.5E-03	5.3E-03	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		3E-03	3E-03	5E-03	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

CHR_ATC	25550	Exposure Duration	CHRONIC
CHR_ATnc	2190	CHR_IRPfr	223500
CHR_ED	6	CHR_IRPvg	201000
CHR_EF	270	CHR_Flp	0.25
CHR_BW	15		

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table E-41a

Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	1.5E-02			1.5E-02	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-02	0E+00	0E+00	2E-02	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-41b

Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - Exposure Unit 3 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.0E-02	1.0E+00	1.0E-02	-	-		-	4.3E-04	3.1E-04	7.4E-04	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		4E-04	3E-04	7E-04	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12a for definitions):

INF_ATC	25550	INF_IRPfr	155250
INF_ATnc	365	INF_IRPvg	109350
INF_ED	1	INF_Flp	0.25
INF_EF	270		
INF_BW	6.75		

Exposure Duration: SUBCHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table E-42

Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] (L/cm²/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	2.0E-02			2.0E-02	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-02	0E+00	0E+00	2E-02	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm²/event)	L/cm²/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m³)	mg/m³:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m³)	VF:	Volatilization factor (m³/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m³)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Exposure Duration CHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table E-43

Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm^2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	2.0E-02			2.0E-02	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-02	0E+00	0E+00	2E-02	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

CIo_ATC	25550	CIo_ETgwi	–
CIo_ATnc	9125	CIo_EvFgw	–
CIo_BW	70	CIo_FIgw	1
CIo_ED	25	CIo_IRgw	2
CIo_EFgw	250	CIo_Sagw	–
CIo_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table E-44

Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - Exposure Unit 3 - UCL COPC Concentrations - ARCADIS Comparative Scenario

Human Health Risk Assessment - ARCADIS Comparative Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK				Percent Total ELCR	NON-CANCER HAZARD				Percent Total HI
					Route-Specific Risk			Calculated Risk		Route-Specific Hazard			Calculated Hazard	
					Oral	Dermal [c]	Inhalation (trench air) [c]			Oral	Dermal [c]	Inhalation (trench air) [c]		
Miscellaneous														
Sulfolane	1.0E-02		2.0E-07		-			-	-	1.8E-06			1.8E-06	100%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		2E-06	0E+00	0E+00	2E-06	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:

[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12a for definitions):

Exposure Duration SUBCHRONIC

CST_ATC	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_Flgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Equations:

$ELCRo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

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Appendix F

Estimated Risks/Hazards Using Maximum COPC Concentrations – ARCADIS Scenario

Table F-1a

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Subsurface Soil (0 to 15 ft below ground surface) - Maximum COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	1.8E+01	1.0E+06	1.8E-05			6.1E-07	3.7E-08	1.5E-08	6.6E-07	69%	5.7E-03	3.5E-04	1.7E-02	2.3E-02	8.2%
Chromium, Total	5.1E+01	1.0E+06	5.1E-05			-	-	-	-	-	5.5E-05	-	-	5.5E-05	<1%
Iron	2.9E+04	1.0E+06	2.9E-02			-	-	-	-	-	6.7E-02	-	-	6.7E-02	24.0%
Nickel	3.8E+01	1.0E+06	3.8E-05			-	-	2.0E-09	2.0E-09	<1%	3.1E-03	-	6.0E-03	9.1E-03	3.3%
VOCs															
1,2,4-Trimethylbenzene	2.1E+02	8.5E+03	2.4E-02		V	-	-	-	-	-	-	-	4.9E-03	4.9E-03	1.8%
1,3,5-Trimethylbenzene	8.1E+01	7.1E+03	1.1E-02		V	-	-	-	-	-	1.3E-03	-	1.6E-02	1.8E-02	6.3%
4-Isopropyltoluene (p-cymene)	2.0E+01	9.4E+03	2.2E-03		V	-	-	-	-	-	-	-	-	-	-
Benzene	8.2E+01	3.8E+03	2.2E-02		V	1.0E-07	-	3.4E-08	1.4E-07	14%	1.3E-02	-	3.8E-03	1.7E-02	6.1%
Cyclohexane	4.5E+01	1.1E+03	4.0E-02		V	-	-	-	-	-	-	-	9.5E-05	9.5E-05	<1%
Ethylbenzene	1.1E+02	6.1E+03	1.8E-02		V	2.8E-08	-	9.3E-09	3.7E-08	4%	3.6E-03	-	2.9E-05	3.6E-03	1.3%
Isopropylbenzene (cumene)	4.2E+01	6.7E+03	6.2E-03		V	-	-	-	-	-	1.7E-04	-	9.9E-04	1.2E-03	<1%
Methylene chloride	1.9E-01	2.4E+03	8.0E-05		V	3.3E-11	-	7.6E-12	4.0E-11	<1%	5.1E-06	-	3.8E-07	5.4E-06	<1%
n-Butylbenzene	1.1E+02	8.8E+03	1.2E-02		V	-	-	-	-	-	1.7E-03	-	-	1.7E-03	<1%
n-Hexane	1.3E+01	8.9E+02	1.5E-02		V	-	-	-	-	-	7.0E-05	-	1.0E-04	1.7E-04	<1%
n-Propylbenzene	7.3E+01	7.5E+03	9.7E-03		V	-	-	-	-	-	1.2E-03	2.4E-04	1.4E-04	1.5E-03	<1%
sec-Butylbenzene	2.5E+01	8.1E+03	3.1E-03		V	-	-	-	-	-	-	-	-	-	-
Toluene	3.9E+02	4.6E+03	8.5E-02		V	-	-	-	-	-	7.9E-04	-	2.4E-04	1.0E-03	<1%
Xylenes	7.1E+02	6.3E+03	1.1E-01		V	-	-	-	-	-	2.8E-03	-	4.0E-03	6.9E-03	2.5%
SVOCs															
1-Methylnaphthalene	8.9E+01	6.3E+04	1.4E-03		V	5.9E-08	-	-	5.9E-08	6%	2.0E-03	-	-	2.0E-03	<1%
2-Methylnaphthalene	2.4E+02	6.2E+04	3.8E-03		V	-	-	-	-	-	9.7E-02	-	-	9.7E-02	34.8%
PAHs															
Benzo (a) anthracene	9.9E-02	1.0E+06	9.9E-08			*	*	*	*	-	-	-	-	-	-
Benzo (a) pyrene	9.5E-02	1.0E+06	9.5E-08			*	*	*	*	-	-	-	-	-	-
Benzo (b) fluoranthene	1.1E-01	1.0E+06	1.1E-07			*	*	*	*	-	-	-	-	-	-
Benzo (k) fluoranthene	4.0E-02	1.0E+06	4.0E-08			*	*	*	*	-	-	-	-	-	-
Chrysene	7.8E-01	1.0E+06	7.8E-07			*	*	*	*	-	-	-	-	-	-
Dibenzo (a,h) anthracene	1.8E-02	1.0E+06	1.8E-08			*	*	*	*	-	-	-	-	-	-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.0E+06	6.9E-08			*	*	*	*	-	-	-	-	-	-
Naphthalene	1.3E+02	5.0E+04	2.5E-03		V	-	-	1.7E-08	1.7E-08	2%	1.0E-02	2.7E-03	1.2E-02	2.5E-02	8.9%
Total Benzo(a)pyrene TEQ	2.3E-01	1.0E+06	2.3E-07			3.8E-08	1.0E-08	5.0E-11	4.8E-08	5%	-	-	-	-	-
Miscellaneous															
Sulfolane	1.8E+01	1.0E+06	1.8E-05			-	-	-	-	-	3.0E-04	-	-	3.0E-04	<1%
GRO	7.7E+03	1.0E+06	7.7E-03			-	-	-	-	-	-	-	-	-	-
DRO	1.9E+04	1.0E+06	1.9E-02			-	-	-	-	-	-	-	-	-	-
RRO	6.5E+04	1.0E+06	6.5E-02			-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard						8E-07	5E-08	8E-08	1E-06		2E-01	3E-03	7E-02	3E-01	
Total Risk or Hazard Excluding Arsenic						2E-07	1E-08	6E-08	3E-07		2E-01	3E-03	5E-02	3E-01	

Table F-1a

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Subsurface Soil (0 to 15 ft below ground surface) - Maximum COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/m$^{3:}$	Milligram(s) per cubic meter
ELCR:	Excess lifetime cancer risk (unitless)	PAH:	Polycyclic aromatic hydrocarbon
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
mg/kg:	Milligram(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk
m³/kg:	Cubic meter(s) per kilogram		

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

CST_ATc	25550	CST_ET	1
CST_ATnc	365	CST_EvFs	1
CST_AF	0.3	CST_FI	1
CST_BW	70	CST_IRs	330
CST_ED	1	CST_PEF	1.00E+06
CST_EF	125	CST_SA	2230

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCs × FI × IRs × EF × ED × CSFo) / (1,000,000 × BW × ATc)

ELCRd = ([EPCs × AF × ABSd] × SA × EvFs × EF × ED × CSFd) / (1,000,000 × BW × ATc)

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCs × FI × IRs × EF × ED) / (1,000,000 × BW × ATnc × RfDo)

HQd = ([EPCs × AF ×ABSd]) × SA ×EvFs × EF × ED) / (1,000,000 × BW × ATnc × RfDa)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table F-1b

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Groundwater in a Trench - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCta [a] (mg/m3)		CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (trench air)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (trench air)	Calculated Hazard	Percent Total HI
Metals															
Barium	2.6E-01		1.0E-06			-	-	-	-	-	6.8E-05	5.8E-04		6.5E-04	<1%
Iron	2.8E+01		1.0E-06			-	-	-	-	-	7.3E-04	4.4E-04	-	1.2E-03	<1%
Lead	1.2E-03		1.0E-07			-	-	-	-	-	-	-	-	-	-
VOCs															
1,2,4-Trimethylbenzene	1.1E-01	7.5E+00	2.6E-04	8.5E-01	V	-	-	-	-	-	-	-	1.7E-01	1.7E-01	2.0%
1,3,5-Trimethylbenzene	1.2E-01	7.6E+00	1.8E-04	9.2E-01	V	-	-	-	-	-	2.2E-05	2.4E-03	1.3E+00	1.3E+00	15.0%
4-Isopropyltoluene (p-cymene	3.3E-02	7.2E+00	5.0E-04	2.4E-01	V	-	-	-	-	-	-	-	-	-	-
Benzene	1.3E+00	9.3E+00	2.3E-05	1.2E+01	V	1.9E-08	2.7E-07	2.0E-05	2.0E-05	73%	2.4E-03	3.4E-02	2.2E+00	2.3E+00	25.9%
Ethylbenzene	1.8E-01	8.0E+00	8.8E-05	1.4E+00	V	5.1E-10	2.7E-08	7.4E-07	7.7E-07	3%	6.5E-05	3.4E-03	2.3E-03	5.8E-03	<1%
n-Propylbenzene	8.0E-02	7.6E+00	2.8E-04	6.1E-01	V	-	-	-	-	-	1.5E-05	2.5E-03	8.7E-03	1.1E-02	<1%
Toluene	1.4E+00	8.6E+00	5.2E-05	1.2E+01	V	-	-	-	-	-	3.2E-05	1.0E-03	3.5E-02	3.6E-02	<1%
Xylenes	1.2E+00	8.0E+00	9.5E-05	9.5E+00	V	-	-	-	-	-	5.4E-05	3.1E-03	3.4E-01	3.4E-01	3.9%
SVOCs															
1-Methylnaphthalene	3.5E-02	6.3E+00	3.3E-04	2.2E-01	V	2.6E-10	5.2E-08	-	5.2E-08	<1%	9.1E-06	1.8E-03	-	1.8E-03	<1%
2-Methylnaphthalene	2.5E-02	6.3E+00	3.2E-04	1.6E-01	V	-	-	-	-	-	1.1E-04	2.2E-02	-	2.2E-02	<1%
PAHs															
Naphthalene	1.5E-01	6.6E+00	9.7E-05	9.6E-01	V	-	-	6.6E-06	6.6E-06	24%	1.3E-04	7.7E-03	4.6E+00	4.6E+00	52.3%
Miscellaneous															
Sulfolane	8.3E-01		2.0E-07			-	-	-	-	-	1.5E-04	1.8E-05	-	1.7E-04	<1%
GRO	2.1E+01		NA			-	-	-	-	-	-	-	-	-	-
DRO	1.5E+00		NA			-	-	-	-	-	-	-	-	-	-
RRO	2.8E-01		NA			-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard						2E-08	3E-07	3E-05	3E-05		4E-03	8E-02	8.6E+00	8.7E+00	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:

[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

Table F-1b

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Groundwater in a Trench - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Parameters (see Table 3-12b for definitions):

CST_ATc	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_FIgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRinc_gw × EFgw × ED × CSFo) / (BW × ATc)

ELCRd = (EPCgw × DA × SAgw × EvFgw × EFgw × ED × CSFd) / (BW × ATc)

ELCRta (VOCs) = ([EPCgw × VF] × EFgw × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCgw × FIgw × IRinc_gw × EFgw × ED) / (BW × ATnc × RfDo)

HQd = (EPCgw × DA ×SAgw ×EvFgw × EFgw × ED) / (BW × ATnc × RfDa)

HQta (VOCs) = ([EPCgw × VF] × ET × EFgw × ED) / (24 × ATnc × RfC)

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Appendix G

Estimated Risks/Hazards Using Maximum COPC Concentrations – ARCADIS Scenario

Table G-1
Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Indoor Worker Exposed to Indoor Air - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (ug/L) [b]	EPCsg (mg/m^3) [a]	AF [a]	EPCia (mg/m^3) [a]		CANCER RISK Route-Specific Risk Inhalation (indoor air)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Inhalation (indoor air)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Metals											
Barium	2.6E+02							-			-
Iron	2.8E+04							-			-
Lead	1.2E+00							-			-
VOCs											
1,2,4-Trimethylbenzene	1.1E+02	7.3E+00	1.1E-05	8.2E-05	V	-		-	2.7E-03	2.7E-03	14.1%
1,3,5-Trimethylbenzene	1.2E+02	7.5E+00	1.3E-05	9.5E-05	V	-		-	-		-
4-Isopropyltoluene (p-cymene)	3.3E+01				V			-			-
Benzene	1.3E+03	1.2E+02	1.0E-05	1.2E-03	V	7.9E-07	7.9E-07	80%	9.4E-03	9.4E-03	49.7%
Ethylbenzene	1.8E+02	1.8E+01	7.5E-06	1.4E-04	V	2.8E-08	2.8E-08	3%	3.1E-05	3.1E-05	<1%
n-Propylbenzene	8.0E+01	9.4E+00	6.5E-06	6.0E-05	V	-		-	1.4E-05	1.4E-05	<1%
Toluene	1.4E+03	1.4E+02	8.7E-06	1.2E-03	V	-		-	5.4E-05	5.4E-05	<1%
Xylenes	1.2E+03	1.1E+02	8.4E-06	9.5E-04	V	-		-	2.2E-03	2.2E-03	11.5%
SVOCs											
1-Methylnaphthalene	3.5E+01	1.1E-01	1.1E-04	1.2E-05	V	-		-	-		-
2-Methylnaphthalene	2.5E+01	7.9E-02	1.1E-04	8.8E-06	V	-		-	-		-
PAHs											
Naphthalene	1.5E+02	6.3E-01	9.4E-05	6.0E-05	V	1.7E-07	1.7E-07	17%	4.6E-03	4.6E-03	24.1%
Miscellaneous											
Sulfolane	8.3E+02							-			-
GRO	2.1E+04							-			-
DRO	1.5E+03							-			-
RRO	2.8E+02							-			-
Total Risk or Hazard						1E-06	1E-06		2E-02	2E-02	

Abbreviations:

-:	Not applicable	ug/L:	Microgram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCgw:	Exposure point concentration in groundwater (ug/L)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	SVOCs:	Semi-volatile organic compounds
EPCsg:	Exposure point concentration in soil gas (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
AF:	Attenuation factor (unitless)		

Notes:

[a] Modeled from groundwater data using Johnson & Ettinger Soil Gas Model (USEPA, 2004). A commercial air exchange rate of 1 per hour was used. Results presented in Appendix C.
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

CI_ATC	25550
CI_ATnc	9125
CI_ED	25
CI_EF	250
CI_ET	8

Exposure Duration CHRONIC

Equations:

ELCRia (VOCs) = ([EPCsg × AF] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQia (VOCs) = ([EPCsg × AF] × ET × EF × ED) / (24 × ATnc × RfC)

Table G-2

Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.6E+00	1.3E+09	5.8E-09			4.0E-06	5.3E-07	2.0E-09	4.5E-06	97%	2.5E-02	3.3E-03	8.8E-05	2.8E-02	52.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08			-	-	-	-	-	1.3E-05	-	-	1.3E-05	<1%
Iron	1.7E+04	1.3E+09	1.3E-05			-	-	-	-	-	2.4E-02	-	-	2.4E-02	44.3%
Lead							-			-		-			-
Nickel	2.0E+01	1.3E+09	1.5E-08			-	-	3.3E-10	3.3E-10	<1%	9.9E-04	-	3.9E-05	1.0E-03	1.9%
VOCs															
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V	-	-	-	-	-	2.2E-06	-	-	2.2E-06	<1%
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V	-	-	-	-	-	-	-	-	-	-
Benzene	5.1E-02	3.8E+03	1.3E-05		V	9.8E-10	-	8.5E-09	9.5E-09	<1%	1.2E-05	-	1.0E-04	1.1E-04	<1%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V	-	-	-	-	-	-	-	1.0E-06	1.0E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V	8.4E-10	-	7.3E-09	8.1E-09	<1%	2.1E-06	-	8.2E-06	1.0E-05	<1%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V	1.6E-10	-	9.8E-10	1.1E-09	<1%	9.8E-07	-	5.8E-06	6.8E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V	-	-	-	-	-	1.9E-06	-	4.2E-05	4.4E-05	<1%
Toluene	8.2E-02	4.6E+03	1.8E-05		V	-	-	-	-	-	1.0E-06	-	8.1E-07	1.8E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V	-	-	-	-	-	3.6E-06	-	2.7E-04	2.7E-04	<1%
SVOCs															
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V	2.5E-09	-	-	2.5E-09	<1%	3.4E-06	-	-	3.4E-06	<1%
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V	-	-	-	-	-	6.7E-05	-	-	6.7E-05	<1%
PAHs															
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11			*	*	*	*	-	-	-	-	-	-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11			*	*	*	*	-	-	-	-	-	-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11			*	*	*	*	-	-	-	-	-	-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11			*	*	*	*	-	-	-	-	-	-
Chrysene	6.6E-02	1.3E+09	5.0E-11			*	*	*	*	-	-	-	-	-	-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11			*	*	*	*	-	-	-	-	-	-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11			*	*	*	*	-	-	-	-	-	-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V	-	-	3.3E-09	3.3E-09	<1%	2.9E-06	1.7E-06	9.0E-05	9.5E-05	<1%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11			8.1E-08	4.7E-08	2.2E-12	1.3E-07	3%	-	-	-	-	-
Miscellaneous															
Sulfolane	3.8E-02	1.3E+09	2.9E-11			-	-	-	-	-	3.7E-06	-	-	3.7E-06	<1%
GRO	5.4E+00	1.3E+09	4.1E-09			-	-	-	-	-	-	-	-	-	-
DRO	2.1E+02	1.3E+09	1.6E-07			-	-	-	-	-	-	-	-	-	-
RRO	1.9E+03	1.3E+09	1.4E-06			-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard						4E-06	6E-07	2E-08	5E-06		5E-02	3E-03	6E-04	5E-02	
Total Risk or Hazard Excluding Arsenic						9E-08	5E-08	2E-08	2E-07		2E-02	2E-06	6E-04	3E-02	

Table G-2

Chronic Risk and Hazard Estimates for the Onsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

		Exposure Duration	CHRONIC
CIo_ATc	25550	CIo_ET	8
CIo_ATnc	9125	CIo_EvFs	1
CIo_AF	0.2	CIo_FI	1
CIo_BW	70	CIo_IRs	100
CIo_ED	25	CIo_PEF	1316000000
CIo_EF	250	CIo_SA	2230

Equations:

ELCRo = (EPCs × FI × IRs × EF × ED × CSFo) / (1,000,000 × BW × ATc)
ELCRd = ([EPCs × AF × ABSd] × SA × EvFs × EF × ED × CSFd) / (1,000,000 × BW × ATc)
ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCs × FI × IRs × EF × ED) / (1,000,000 × BW × ATnc × RfDo)
HQd = ([EPCs × AF ×ABSd]) × SA ×EvFs × EF × ED) / (1,000,000 × BW × ATnc × RfDa)
HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table G-3a

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Subsurface Soil (0 to 15 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.3E+00	1.0E+06	7.3E-06			2.5E-07	1.5E-08	6.4E-09	2.7E-07	94%	2.4E-03	1.4E-04	7.0E-03	9.5E-03	16.5%
Chromium, Total	1.7E+01	1.0E+06	1.7E-05			-	-	-	-	-	1.8E-05	-	-	1.8E-05	<1%
Iron	1.5E+04	1.0E+06	1.5E-02			-	-	-	-	-	3.5E-02	-	-	3.5E-02	60.5%
Nickel	1.9E+01	1.0E+06	1.9E-05			-	-	1.0E-09	1.0E-09	<1%	1.5E-03	-	3.0E-03	4.5E-03	7.9%
VOCs															
1,2,4-Trimethylbenzene	2.2E+01	8.5E+03	2.6E-03		V	-	-	-	-	-	-	-	5.3E-04	5.3E-04	<1%
1,3,5-Trimethylbenzene	8.3E+00	7.1E+03	1.2E-03		V	-	-	-	-	-	1.3E-04	-	1.7E-03	1.8E-03	3.1%
4-Isopropyltoluene (p-cymene)	2.0E+00	9.4E+03	2.2E-04		V	-	-	-	-	-	-	-	-	-	-
Benzene	3.1E+00	3.8E+03	8.2E-04		V	4.0E-09	-	1.3E-09	5.3E-09	2%	5.1E-04	-	1.5E-04	6.5E-04	1.1%
Cyclohexane	5.6E+00	1.1E+03	5.0E-03		V	-	-	-	-	-	-	-	1.2E-05	1.2E-05	<1%
Ethylbenzene	8.7E+00	6.1E+03	1.4E-03		V	2.2E-09	-	7.2E-10	2.9E-09	<1%	2.8E-04	-	2.3E-06	2.8E-04	<1%
Isopropylbenzene (cumene)	4.0E+00	6.7E+03	5.9E-04		V	-	-	-	-	-	1.6E-05	-	9.4E-05	1.1E-04	<1%
Methylene chloride	2.9E-01	2.4E+03	1.2E-04		V	5.0E-11	-	1.2E-11	6.2E-11	<1%	7.8E-06	-	5.8E-07	8.4E-06	<1%
n-Butylbenzene	7.6E+00	8.8E+03	8.7E-04		V	-	-	-	-	-	1.2E-04	-	-	1.2E-04	<1%
n-Hexane	2.4E+00	8.9E+02	2.7E-03		V	-	-	-	-	-	1.3E-05	-	1.9E-05	3.2E-05	<1%
n-Propylbenzene	7.2E+00	7.5E+03	9.6E-04		V	-	-	-	-	-	1.2E-04	2.4E-05	1.4E-05	1.5E-04	<1%
sec-Butylbenzene	6.6E+00	8.1E+03	8.1E-04		V	-	-	-	-	-	-	-	-	-	-
Toluene	1.7E+01	4.6E+03	3.8E-03		V	-	-	-	-	-	3.5E-05	-	1.1E-05	4.6E-05	<1%
Xylenes	4.7E+01	6.3E+03	7.5E-03		V	-	-	-	-	-	1.9E-04	-	2.7E-04	4.6E-04	<1%
SVOCs															
1-Methylnaphthalene	4.6E+00	6.3E+04	7.3E-05		V	3.1E-09	-	-	3.1E-09	1%	1.1E-04	-	-	1.1E-04	<1%
2-Methylnaphthalene	8.6E+00	6.2E+04	1.4E-04		V	-	-	-	-	-	3.5E-03	-	-	3.5E-03	6.0%
PAHs															
Benzo (a) anthracene	1.2E-02	1.0E+06	1.2E-08			*	*	*	*	-	-	-	-	-	-
Benzo (a) pyrene	1.2E-02	1.0E+06	1.2E-08			*	*	*	*	-	-	-	-	-	-
Benzo (b) fluoranthene	2.1E-02	1.0E+06	2.1E-08			*	*	*	*	-	-	-	-	-	-
Benzo (k) fluoranthene	1.9E-02	1.0E+06	1.9E-08			*	*	*	*	-	-	-	-	-	-
Chrysene	3.5E-02	1.0E+06	3.5E-08			*	*	*	*	-	-	-	-	-	-
Dibenzo (a,h) anthracene	9.9E-03	1.0E+06	9.9E-09			*	*	*	*	-	-	-	-	-	-
Indeno (1,2,3-cd) pyrene	1.1E-02	1.0E+06	1.1E-08			*	*	*	*	-	-	-	-	-	-
Naphthalene	4.4E+00	5.0E+04	8.8E-05		V	-	-	6.1E-10	6.1E-10	<1%	3.5E-04	9.3E-05	4.2E-04	8.6E-04	1.5%
Total Benzo(a)pyrene TEQ	2.6E-02	1.0E+06	2.6E-08			4.3E-09	1.1E-09	5.8E-12	5.5E-09	2%	-	-	-	-	-
Miscellaneous															
Sulfolane	4.5E-01	1.0E+06	4.5E-07			-	-	-	-	-	7.3E-06	-	-	7.3E-06	<1%
GRO	8.1E+02	1.0E+06	8.1E-04			-	-	-	-	-	-	-	-	-	-
DRO	2.1E+03	1.0E+06	2.1E-03			-	-	-	-	-	-	-	-	-	-
RRO	8.2E+03	1.0E+06	8.2E-03			-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard						3E-07	2E-08	1E-08	3E-07		4E-02	3E-04	1E-02	6E-02	
Total Risk or Hazard Excluding Arsenic						1E-08	1E-09	4E-09	2E-08		4E-02	1E-04	6E-03	5E-02	

Table G-3a

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Subsurface Soil (0 to 15 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/m$^{3:}$	Milligram(s) per cubic meter
ELCR:	Excess lifetime cancer risk (unitless)	PAH:	Polycyclic aromatic hydrocarbon
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
mg/kg:	Milligram(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk
m³/kg:	Cubic meter(s) per kilogram		

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

CST_ATc	25550	CST_ET	1
CST_ATnc	365	CST_EvFs	1
CST_AF	0.3	CST_FI	1
CST_BW	70	CST_IRs	330
CST_ED	1	CST_PEF	1.00E+06
CST_EF	125	CST_SA	2230

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCs × FI × IRs × EF × ED × CSFo) / (1,000,000 × BW × ATc)

ELCRd = ([EPCs × AF × ABSd] × SA × EvFs × EF × ED × CSFd) / (1,000,000 × BW × ATc)

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCs × FI × IRs × EF × ED) / (1,000,000 × BW × ATnc × RfDo)

HQd = ([EPCs × AF ×ABSd]) × SA ×EvFs × EF × ED) / (1,000,000 × BW × ATnc × RfDa)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table G-3b

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Groundwater in a Trench - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCta [a] (mg/m3)		CANCER RISK: Route-Specific Risk Oral	Dermal	Inhalation (trench air)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal	Inhalation (trench air)	Calculated Hazard	Percent Total HI
Metals															
Barium	2.6E-01		1.0E-06			-	-	-	-	-	6.8E-05	5.8E-04		6.5E-04	<1%
Iron	2.8E+01		1.0E-06			-	-	-	-	-	7.3E-04	4.4E-04	-	1.2E-03	<1%
Lead	1.2E-03		1.0E-07			-	-	-	-	-	-	-	-	-	-
VOCs															
1,2,4-Trimethylbenzene	1.1E-01	7.5E+00	2.6E-04	8.5E-01	V	-	-	-	-	-	-	-	1.7E-01	1.7E-01	2.0%
1,3,5-Trimethylbenzene	1.2E-01	7.6E+00	1.8E-04	9.2E-01	V	-	-	-	-	-	2.2E-05	2.4E-03	1.3E+00	1.3E+00	15.0%
4-Isopropyltoluene (p-cymene)	3.3E-02	7.2E+00	5.0E-04	2.4E-01	V	-	-	-	-	-	-	-	-	-	-
Benzene	1.3E+00	9.3E+00	2.3E-05	1.2E+01	V	1.9E-08	2.7E-07	2.0E-05	2.0E-05	73%	2.4E-03	3.4E-02	2.2E+00	2.3E+00	25.9%
Ethylbenzene	1.8E-01	8.0E+00	8.8E-05	1.4E+00	V	5.1E-10	2.7E-08	7.4E-07	7.7E-07	3%	6.5E-05	3.4E-03	2.3E-03	5.8E-03	<1%
n-Propylbenzene	8.0E-02	7.6E+00	2.8E-04	6.1E-01	V	-	-	-	-	-	1.5E-05	2.5E-03	8.7E-03	1.1E-02	<1%
Toluene	1.4E+00	8.6E+00	5.2E-05	1.2E+01	V	-	-	-	-	-	3.2E-05	1.0E-03	3.5E-02	3.6E-02	<1%
Xylenes	1.2E+00	8.0E+00	9.5E-05	9.5E+00	V	-	-	-	-	-	5.4E-05	3.1E-03	3.4E-01	3.4E-01	3.9%
SVOCs															
1-Methylnaphthalene	3.5E-02	6.3E+00	3.3E-04	2.2E-01	V	2.6E-10	5.2E-08	-	5.2E-08	<1%	9.1E-06	1.8E-03	-	1.8E-03	<1%
2-Methylnaphthalene	2.5E-02	6.3E+00	3.2E-04	1.6E-01	V	-	-	-	-	-	1.1E-04	2.2E-02	-	2.2E-02	<1%
PAHs															
Naphthalene	1.5E-01	6.6E+00	9.7E-05	9.6E-01	V	-	-	6.6E-06	6.6E-06	24%	1.3E-04	7.7E-03	4.6E+00	4.6E+00	52.3%
Miscellaneous															
Sulfolane	8.3E-01		2.0E-07			-	-	-	-	-	1.5E-04	1.8E-05	-	1.7E-04	<1%
GRO	2.1E+01		NA			-	-	-	-	-	-	-	-	-	-
DRO	1.5E+00		NA			-	-	-	-	-	-	-	-	-	-
RRO	2.8E-01		NA			-	-	-	-	-	-	-	-	-	-
Total Risk or Hazard						2E-08	3E-07	3E-05	3E-05		4E-03	8E-02	9E+00	9E+00	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:

[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

Table G-3b

Subchronic Risk and Hazard Estimates for the Onsite Construction/Trench Worker Exposed to Groundwater in a Trench - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Parameters (see Table 3-12b for definitions):

CST_ATc	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_FIgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Exposure Duration SUBCHRONIC

Equations:

ELCRo = (EPCgw × FIgw × IRinc_gw × EFgw × ED × CSFo) / (BW × ATc)

ELCRd = (EPCgw × DA × SAgw × EvFgw × EFgw × ED × CSFd) / (BW × ATc)

ELCRta (VOCs) = ([EPCgw × VF] × EFgw × ED × ET × IUR × 1000) / (24 × ATc)

HQo = (EPCgw × FIgw × IRinc_gw × EFgw × ED) / (BW × ATnc × RfDo)

HQd = (EPCgw × DA ×SAgw ×EvFgw × EFgw × ED) / (BW × ATnc × RfDa)

HQta (VOCs) = ([EPCgw × VF] × ET × EFgw × ED) / (24 × ATnc × RfC)

Table G-4
Chronic Risk and Hazard Estimates for the Onsite Adult Visitor Exposed to Indoor Air - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (ug/L) [b]	EPCsg (mg/m^3) [a]	AF [a]	EPCia (mg/m^3) [a]		CANCER RISK: Route-Specific Risk Inhalation (indoor air)	CANCER RISK: Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Inhalation (indoor air)	NON-CANCER HAZARD: Calculated Hazard	Percent Total HI
Metals											
Barium	2.6E+02							-			-
Iron	2.8E+04							-			-
Lead	1.2E+00							-			-
VOCs											
1,2,4-Trimethylbenzene	1.1E+02	7.3E+00	1.1E-05	8.2E-05	V	-		-	3.2E-05	3.2E-05	14.1%
1,3,5-Trimethylbenzene	1.2E+02	7.5E+00	1.3E-05	9.5E-05	V	-		-	-		-
4-Isopropyltoluene (p-cymene)	3.3E+01				V			-			-
Benzene	1.3E+03	1.2E+02	1.0E-05	1.2E-03	V	1.1E-08	1.1E-08	80%	1.1E-04	1.1E-04	49.7%
Ethylbenzene	1.8E+02	1.8E+01	7.5E-06	1.4E-04	V	4.0E-10	4.0E-10	3%	3.7E-07	3.7E-07	<1%
n-Propylbenzene	8.0E+01	9.4E+00	6.5E-06	6.0E-05	V	-		-	1.7E-07	1.7E-07	<1%
Toluene	1.4E+03	1.4E+02	8.7E-06	1.2E-03	V	-		-	6.5E-07	6.5E-07	<1%
Xylenes	1.2E+03	1.1E+02	8.4E-06	9.5E-04	V	-		-	2.6E-05	2.6E-05	11.5%
SVOCs											
1-Methylnaphthalene	3.5E+01	1.1E-01	1.1E-04	1.2E-05	V	-		-	-		-
2-Methylnaphthalene	2.5E+01	7.9E-02	1.1E-04	8.8E-06	V	-		-	-		-
PAHs											
Naphthalene	1.5E+02	6.3E-01	9.4E-05	6.0E-05	V	2.4E-09	2.4E-09	17%	5.5E-05	5.5E-05	24.1%
Miscellaneous											
Sulfolane	8.3E+02							-			-
GRO	2.1E+04							-			-
DRO	1.5E+03							-			-
RRO	2.8E+02							-			-
Total Risk or Hazard						1E-08	1E-08		2E-04	2E-04	

Abbreviations:

-:	Not applicable	ug/L:	Microgram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCgw:	Exposure point concentration in groundwater (ug/L)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	SVOCs:	Semi-volatile organic compounds
EPCsg:	Exposure point concentration in soil gas (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
AF:	Attenuation factor (unitless)		

Table G-4
Chronic Risk and Hazard Estimates for the Onsite Adult Visitor Exposed to Indoor Air - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Notes:

[a] Modeled from groundwater data using Johnson & Ettinger Soil Gas Model (USEPA, 2004). A commercial air exchange rate of 1 per hour was used. Results presented in Appendix C.
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

VIS_ATC	25550
VIS_ATnc	10950
VIS_ED	30
VIS_EF	12
VIS_ET	2

Exposure Duration CHRONIC

Equations:

ELCRia (VOCs) = ([EPCsg × AF] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQia (VOCs) = ([EPCsg × AF] × ET × EF × ED) / (24 × ATnc × RfC)

Table G-5a

Chronic Risk and Hazard Estimates for the Offsite Adult Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.6E+00	1.3E+09	5.8E-09					3.9E-09	3.9E-09	9%			1.4E-04	1.4E-04	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08					-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05					-		-			-		-
Lead										-					-
Nickel	2.0E+01	1.3E+09	1.5E-08					6.3E-10	6.3E-10	1%			6.3E-05	6.3E-05	6.0%
VOCs															
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V			-		-			-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05		V			1.6E-08	1.6E-08	38%			1.6E-04	1.6E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V			-		-			1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V			1.4E-08	1.4E-08	33%			1.3E-05	1.3E-05	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V			1.9E-09	1.9E-09	4%			9.5E-06	9.5E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V			-		-			6.9E-05	6.9E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05		V			-		-			1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V			-		-			4.4E-04	4.4E-04	41.7%
SVOCs															
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V			-		-			-		-
PAHs															
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11					*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11					*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11					*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11					*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11					*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11					*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11					*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V			6.4E-09	6.4E-09	15%			1.5E-04	1.5E-04	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11					4.2E-12	4.2E-12	<1%			-		-
Miscellaneous															
Sulfolane	3.8E-02	1.3E+09	2.9E-11					-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09					-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07					-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06					-		-			-		-
Total Risk or Hazard						0E+00	0E+00	4E-08	4E-08		0E+00	0E+00	1E-03	1E-03	
Total Risk or Hazard Excluding Arsenic						0E+00	0E+00	4E-08	4E-08		0E+00	0E+00	9E-04	9E-04	

Table G-5a

Chronic Risk and Hazard Estimates for the Offsite Adult Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12b for definitions):

ADUR_ATc	25550	ADUR_ET	12
ADUR_ATnc	10950	ADUR_FI	–
ADUR_AF	–	ADUR_IRs	–
ADUR_BW	70	ADUR_PEF	1316000000
ADUR_ED	30	ADUR_SA	–
ADUR_EF	270		

Exposure Duration CHRONIC

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table G-5b
Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	4.7E-01			4.7E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		5E-01	0E+00	0E+00	5E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-5c
Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.7E-01	3.2E-01	5.4E-02	-	-		-	9.1E-04	2.5E-03	3.4E-03	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		9E-04	3E-03	3E-03	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

ADUR_ATC	25550	Exposure Duration	CHRONIC
ADUR_ATnc	10950	ADUR_IRPfr	63000
ADUR_ED	30	ADUR_IRPvg	175000
ADUR_EF	270	ADUR_Flp	0.25
ADUR_BW	70		

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table G-6a

Chronic Risk and Hazard Estimates for the Offsite Child Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR		NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals																
Arsenic	7.6E+00	1.3E+09	5.8E-09					7.9E-10	7.9E-10	9%				1.4E-04	1.4E-04	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08					-		-				-		-
Iron	1.7E+04	1.3E+09	1.3E-05					-		-				-		-
Lead										-						-
Nickel	2.0E+01	1.3E+09	1.5E-08					1.3E-10	1.3E-10	1%				6.3E-05	6.3E-05	6.0%
VOCs																
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V			-		-				-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V			-		-				-		-
Benzene	5.1E-02	3.8E+03	1.3E-05		V			3.3E-09	3.3E-09	38%				1.6E-04	1.6E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V			-		-				1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V			2.8E-09	2.8E-09	33%				1.3E-05	1.3E-05	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V			3.8E-10	3.8E-10	4%				9.5E-06	9.5E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V			-		-				6.9E-05	6.9E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05		V			-		-				1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V			-		-				4.4E-04	4.4E-04	41.7%
SVOCs																
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V			-		-				-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V			-		-				-		-
PAHs																
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11					*		-				-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11					*		-				-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11					*		-				-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11					*		-				-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11					*		-				-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11					*		-				-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11					*		-				-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V			1.3E-09	1.3E-09	15%				1.5E-04	1.5E-04	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11					8.4E-13	8.4E-13	<1%				-		-
Miscellaneous																
Sulfolane	3.8E-02	1.3E+09	2.9E-11					-		-				-		-
GRO	5.4E+00	1.3E+09	4.1E-09					-		-				-		-
DRO	2.1E+02	1.3E+09	1.6E-07					-		-				-		-
RRO	1.9E+03	1.3E+09	1.4E-06					-		-				-		-
Total Risk or Hazard						0E+00	0E+00	9E-09	9E-09			0E+00	0E+00	1E-03	1E-03	
Total Risk or Hazard Excluding Arsenic						0E+00	0E+00	8E-09	8E-09			0E+00	0E+00	9E-04	9E-04	

Table G-6a

Chronic Risk and Hazard Estimates for the Offsite Child Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12b for definitions):

CHR_ATc	25550	CHR_ET	12
CHR_ATnc	2190	CHR_FI	–
CHR_AF	–	CHR_IRs	–
CHR_BW	15	CHR_PEF	1316000000
CHR_ED	6	CHR_SA	–
CHR_EF	270		

Exposure Duration CHRONIC

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table G-6b
Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	1.1E+00			1.1E+00	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		1E+00	0E+00	0E+00	1E+00	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-6c
Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.7E-01	3.2E-01	5.4E-02	-	-		-	4.6E-03	5.4E-03	1.0E-02	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		5E-03	5E-03	1E-02	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

CHR_ATC	25550	Exposure Duration	CHRONIC
CHR_ATnc	2190	CHR_IRPfr	69000
CHR_ED	6	CHR_IRPvg	81000
CHR_EF	270	CHR_Flp	0.25
CHR_BW	15		

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table G-6d

Subchronic Risk and Hazard Estimates for the Offsite Child Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.6E+00	1.3E+09	5.8E-09					7.9E-10	7.9E-10	9%			1.4E-04	1.4E-04	21.3%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08					-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05					-		-			-		-
Lead										-					-
Nickel	2.0E+01	1.3E+09	1.5E-08					1.3E-10	1.3E-10	1%			6.3E-05	6.3E-05	9.4%
VOCs															
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V			-		-			1.2E-04	1.2E-04	17.3%
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05		V			3.3E-09	3.3E-09	38%			6.2E-05	6.2E-05	9.2%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V			-		-			1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V			2.8E-09	2.8E-09	33%			1.5E-06	1.5E-06	<1%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V			3.8E-10	3.8E-10	4%			3.2E-06	3.2E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V			-		-			2.4E-05	2.4E-05	3.6%
Toluene	8.2E-02	4.6E+03	1.8E-05		V			-		-			1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V			-		-			1.1E-04	1.1E-04	16.3%
SVOCs															
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V			-		-			-		-
PAHs															
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11					*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11					*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11					*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11					*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11					*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11					*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11					*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V			1.3E-09	1.3E-09	15%			1.5E-04	1.5E-04	21.8%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11					8.4E-13	8.4E-13	<1%			-		-
Miscellaneous															
Sulfolane	3.8E-02	1.3E+09	2.9E-11					-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09					-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07					-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06					-		-			-		-
Total Risk or Hazard						0E+00	0E+00	9E-09	9E-09		0E+00	0E+00	7E-04	7E-04	
Total Risk or Hazard Excluding Arsenic						0E+00	0E+00	8E-09	8E-09		0E+00	0E+00	5E-04	5E-04	

Table G-6d

Subchronic Risk and Hazard Estimates for the Offsite Child Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12b for definitions):

CHR_ATc	25550	CHR_ET	12
CHR_ATnc	2190	CHR_FI	–
CHR_AF	–	CHR_IRs	–
CHR_BW	15	CHR_PEF	1316000000
CHR_ED	6	CHR_SA	–
CHR_EF	270		

Exposure Duration SUBCHRONIC

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table G-6e
Subchronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	1.1E-01			1.1E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		1E-01	0E+00	0E+00	1E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-6f

Subchronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.7E-01	3.2E-01	5.4E-02	-	-		-	4.6E-04	5.4E-04	1.0E-03	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		5E-04	5E-04	1E-03	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

CHR_ATC	25550	CHR_IRPfr	69000
CHR_ATnc	2190	CHR_IRPvg	81000
CHR_ED	6	CHR_Flp	0.25
CHR_EF	270		
CHR_BW	15		

Exposure Duration SUBCHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp× EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table G-7a

Subchronic Risk and Hazard Estimates for the Offsite Infant Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK: Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.6E+00	1.3E+09	5.8E-09					1.3E-10	1.3E-10	9%			1.4E-04	1.4E-04	21.3%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08					-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05					-		-			-		-
Lead										-					-
Nickel	2.0E+01	1.3E+09	1.5E-08					2.1E-11	2.1E-11	1%			6.3E-05	6.3E-05	9.4%
VOCs															
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V			-		-			1.2E-04	1.2E-04	17.3%
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05		V			5.5E-10	5.5E-10	38%			6.2E-05	6.2E-05	9.2%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V			-		-			1.6E-06	1.6E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V			4.7E-10	4.7E-10	33%			1.5E-06	1.5E-06	<1%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V			6.4E-11	6.4E-11	4%			3.2E-06	3.2E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V			-		-			2.4E-05	2.4E-05	3.6%
Toluene	8.2E-02	4.6E+03	1.8E-05		V			-		-			1.3E-06	1.3E-06	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V			-		-			1.1E-04	1.1E-04	16.3%
SVOCs															
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V			-		-			-		-
PAHs															
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11					*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11					*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11					*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11					*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11					*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11					*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11					*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V			2.1E-10	2.1E-10	15%			1.5E-04	1.5E-04	21.8%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11					1.4E-13	1.4E-13	<1%			-		-
Miscellaneous															
Sulfolane	3.8E-02	1.3E+09	2.9E-11					-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09					-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07					-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06					-		-			-		-
Total Risk or Hazard						0E+00	0E+00	1E-09	1E-09		0E+00	0E+00	7E-04	7E-04	
Total Risk or Hazard Excluding Arsenic						0E+00	0E+00	1E-09	1E-09		0E+00	0E+00	5E-04	5E-04	

Table G-7a

Subchronic Risk and Hazard Estimates for the Offsite Infant Resident Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12b for definitions):

INF_ATc	25550	INF_ET	12
INF_ATnc	365	INF_FI	–
INF_AF	–	INF_IRs	–
INF_BW	6.75	INF_PEF	1316000000
INF_ED	1	INF_SA	–
INF_EF	270		

Exposure Duration SUBCHRONIC

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table G-7b
Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	2.5E-01			2.5E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E-01	0E+00	0E+00	3E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:
ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table G-7c
Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.7E-01	3.2E-01	5.4E-02	-	-		-	6.2E-04	5.0E-04	1.1E-03	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		6E-04	5E-04	1E-03	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

INF_ATC	25550	INF_IRPfr	41850
INF_ATnc	365	INF_IRPvg	33750
INF_ED	1	INF_Flp	0.25
INF_EF	270		
INF_BW	6.75		

Exposure Duration SUBCHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table G-8

Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] (L/cm^2/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	3.3E-01			3.3E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E-01	0E+00	0E+00	3E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-9a

Chronic Risk and Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCs (mg/kg)	VF *or* PEF [a] (m^3/kg)	EPCaa (mg/m^3)	EPCia (mg/m^3) [b]		CANCER RISK Route-Specific Risk Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral [c]	Dermal [c]	Inhalation (ambient)	Calculated Hazard	Percent Total HI
Metals															
Arsenic	7.6E+00	1.3E+09	5.8E-09					2.0E-09	2.0E-09	9%			8.8E-05	8.8E-05	13.6%
Chromium, Total	1.9E+01	1.3E+09	1.5E-08					-		-			-		-
Iron	1.7E+04	1.3E+09	1.3E-05					-		-			-		-
Lead										-					-
Nickel	2.0E+01	1.3E+09	1.5E-08					3.3E-10	3.3E-10	1%			3.9E-05	3.9E-05	6.0%
VOCs															
1,3,5-Trimethylbenzene	2.2E-02	7.1E+03	3.1E-06		V			-		-			-		-
4-Isopropyltoluene (p-cymene)	1.8E-02	9.4E+03	1.9E-06		V			-		-			-		-
Benzene	5.1E-02	3.8E+03	1.3E-05		V			8.5E-09	8.5E-09	38%			1.0E-04	1.0E-04	15.7%
Cyclohexane	2.9E-02	1.1E+03	2.6E-05		V			-		-			1.0E-06	1.0E-06	<1%
Ethylbenzene	2.2E-01	6.1E+03	3.6E-05		V			7.3E-09	7.3E-09	33%			8.2E-06	8.2E-06	1.3%
Methylene chloride	6.0E-02	2.4E+03	2.6E-05		V			9.8E-10	9.8E-10	4%			5.8E-06	5.8E-06	<1%
n-Hexane	1.2E-01	8.9E+02	1.3E-04		V			-		-			4.2E-05	4.2E-05	6.6%
Toluene	8.2E-02	4.6E+03	1.8E-05		V			-		-			8.1E-07	8.1E-07	<1%
Xylenes	7.4E-01	6.3E+03	1.2E-04		V			-		-			2.7E-04	2.7E-04	41.7%
SVOCs															
1-Methylnaphthalene	2.4E-01	6.3E+04	3.8E-06		V			-		-			-		-
2-Methylnaphthalene	2.7E-01	6.2E+04	4.4E-06		V			-		-			-		-
PAHs															
Benzo (a) anthracene	6.1E-02	1.3E+09	4.6E-11					*		-			-		-
Benzo (a) pyrene	9.2E-02	1.3E+09	7.0E-11					*		-			-		-
Benzo (b) fluoranthene	1.6E-02	1.3E+09	1.2E-11					*		-			-		-
Benzo (k) fluoranthene	4.0E-02	1.3E+09	3.1E-11					*		-			-		-
Chrysene	6.6E-02	1.3E+09	5.0E-11					*		-			-		-
Dibenzo (a,h) anthracene	1.7E-02	1.3E+09	1.3E-11					*		-			-		-
Indeno (1,2,3-cd) pyrene	6.9E-02	1.3E+09	5.2E-11					*		-			-		-
Naphthalene	5.9E-02	5.0E+04	1.2E-06		V			3.3E-09	3.3E-09	15%			9.0E-05	9.0E-05	14.0%
Total Benzo(a)pyrene TEQ	3.2E-02	1.3E+09	2.4E-11					2.2E-12	2.2E-12	<1%			-		-
Miscellaneous															
Sulfolane	3.8E-02	1.3E+09	2.9E-11					-		-			-		-
GRO	5.4E+00	1.3E+09	4.1E-09					-		-			-		-
DRO	2.1E+02	1.3E+09	1.6E-07					-		-			-		-
RRO	1.9E+03	1.3E+09	1.4E-06					-		-			-		-
Total Risk or Hazard						0E+00	0E+00	2E-08	2E-08		0E+00	0E+00	6E-04	6E-04	
Total Risk or Hazard Excluding Arsenic						0E+00	0E+00	2E-08	2E-08		0E+00	0E+00	6E-04	6E-04	

Table G-9a

Chronic Risk and Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Surface Soil (0 to 2 ft below ground surface) - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Abbreviations:

-:	Not applicable	mg/kg:	Milligram(s) per kilogram
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	PAH:	Polycyclic aromatic hydrocarbon
EPCia:	Exposure point concentration in indoor air (mg/m^3)	PEF:	Particulate emission factor (m^3/kg)
EPCs:	Exposure point concentration in soil (mg/kg)	VF:	Volatilization factor (m^3/kg)
HI:	Hazard index (unitless)	VOCs:	Volatile organic compounds
HQ:	Hazard quotient (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
m^3/kg:	Cubic meter(s) per kilogram	*	Included in Benzo(a)pyrene TEQ calculated risk

Notes:
[a] Default PEFs and VFs were obtained from USEPA (2011d).
[b] Media evaluated separately.
[c] Incomplete pathway for this receptor.

Parameters (see Table 3-12b for definitions):

		Exposure Duration	CHRONIC
CIo_ATc	25550	CIo_ET	8
CIo_ATnc	9125	CIo_FI	1
CIo_BW	70	CIo_IRs	100
CIo_ED	25	CIo_PEF	1316000000
CIo_EF	250		

Equations:

ELCRaa = ([EPCs / (VF or PEF)] × EF × ED × ET × IUR × 1000) / (24 × ATc)

HQaa = ([EPCs / (VF or PEF)] × ET × EF × ED) / (24 × ATnc × RfC)

Table G-9b

Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm^2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.7E-01					-			-	-	3.3E-01			3.3E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E-01	0E+00	0E+00	3E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

CIo_ATC	25550	CIo_ETgwi	–
CIo_ATnc	9125	CIo_EvFgw	–
CIo_BW	70	CIo_FIgw	1
CIo_ED	25	CIo_IRgw	2
CIo_EFgw	250	CIo_Sagw	–
CIo_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-10

Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - Exposure Unit 1 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK: Route-Specific Risk Oral	Dermal [c]	Inhalation (domestic use) [c]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal [c]	Inhalation (domestic use) [c]	Calculated Hazard	Percent Total HI
Miscellaneous														
Sulfolane	1.7E-01		2.0E-07		-			-	-	3.1E-05			3.1E-05	100%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		3E-05	0E+00	0E+00	3E-05	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	mg/m^3:	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:

[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

Exposure Duration SUBCHRONIC

CST_ATC	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_Flgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Equations:

$ELCRo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-11

Chronic Hazard Estimates for the Offsite Adult Recreator Exposed to Surface Water - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCsw (mg/L)	VF [a] (L/m^3)	DA [b] (L/cm2/event)	CANCER RISK: Route-Specific Risk Oral [c]	Dermal [d]	Inhalation [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [d]	Inhalation [d]	Calculated Hazard	Percent Total HI
Miscellaneous													
Sulfolane	1.6E-01			-			-	-	1.9E-04			1.9E-04	100%
Total Risk or Hazard				0E+00	0E+00	0E+00	0E+00		2E-04	0E+00	0E+00	2E-04	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCsw:	Exposure point concentration in surface water (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTsw) as shown for this receptor below.

[c] This exposure scenario assumes recreational contact exposures including swimming, walking, wading, and splashing.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

			Exposure Duration CHRONIC
AREC_ATC	25550	AREC_ET	0.5
AREC_ATnc	10950	AREC_EvFsw	–
AREC_BW	70	AREC_FIsw	1
AREC_ED	30	AREC_IRinc_sw	0.021
AREC_EFsw	30	AREC_SAsw	–
AREC_EvTsw	–		

Equations:

$ELCRo = (EPCsw \times FIsw \times IRinc\_sw \times ET \times EFsw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCsw \times FIsw \times IRinc\_sw \times ET \times EFsw \times ED) / (BW \times ATnc \times RfDo)$

Table G-12a

Chronic Hazard Estimates for the Offsite Child Recreator Exposed to Surface Water - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCsw (mg/L)	VF [a] (L/m^3)	DA [b] (L/cm2/event)	CANCER RISK: Route-Specific Risk Oral [c]	Dermal [d]	Inhalation [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [d]	Inhalation [d]	Calculated Hazard	Percent Total HI
Miscellaneous													
Sulfolane	1.6E-01			-			-	-	2.1E-03			2.1E-03	100%
Total Risk or Hazard				0E+00	0E+00	0E+00	0E+00		2E-03	0E+00	0E+00	2E-03	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCsw:	Exposure point concentration in surface water (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTsw) as shown for this receptor below.

[c] This exposure scenario assumes recreational contact exposures including swimming, walking, wading, and splashing.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions): Exposure Duration CHRONIC

CREC_ATC	25550	CREC_ET	0.5
CREC_ATnc	2190	CREC_EvFsw	–
CREC_BW	15	CREC_FIsw	1
CREC_ED	6	CREC_IRinc_sw	0.049
CREC_EFsw	30	CREC_SAsw	–
CREC_EvTsw	–		

Equations:

$ELCRo = (EPCsw \times FIsw \times IRinc\_sw \times ET \times EFsw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCsw \times FIsw \times IRinc\_sw \times ET \times EFsw \times ED) / (BW \times ATnc \times RfDo)$

Table G-12b
Subchronic Hazard Estimates for the Offsite Child Recreator Exposed to Surface Water - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCsw (mg/L)	VF [a] (L/m^3)	DA [b] (L/cm2/event)	CANCER RISK: Route-Specific Risk Oral [c]	Dermal [d]	Inhalation [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral [c]	Dermal [d]	Inhalation [d]	Calculated Hazard	Percent Total HI
Miscellaneous													
Sulfolane	1.6E-01			-			-	-	2.1E-04			2.1E-04	100%
Total Risk or Hazard				0E+00	0E+00	0E+00	0E+00		2E-04	0E+00	0E+00	2E-04	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCaa:	Exposure point concentration in ambient air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCsw:	Exposure point concentration in surface water (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTsw) as shown for this receptor below.
[c] This exposure scenario assumes recreational contact exposures including swimming, walking, wading, and splashing.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions): Exposure Duration SUBCHRONIC

CREC_ATC	25550	CREC_ET	0.5
CREC_ATnc	2190	CREC_EvFsw	–
CREC_BW	15	CREC_FIsw	1
CREC_ED	6	CREC_IRinc_sw	0.049
CREC_EFsw	30	CREC_SAsw	–
CREC_EvTsw	–		

Equations:
ELCRo = (EPCsw × FIsw × IRinc_sw × ET × EFsw × ED × CSFo) / (BW × ATc)

HQo = (EPCsw × FIsw × IRinc_sw × ET × EFsw × ED) / (BW × ATnc × RfDo)

Table G-13a

Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	1.6E-01			1.6E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-01	0E+00	0E+00	2E-01	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EgwF \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-13b
Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	5.9E-02	3.2E-01	1.9E-02	-	-		-	3.1E-04	8.7E-04	1.2E-03	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		3E-04	9E-04	1E-03	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

ADUR_ATC	25550	Exposure Duration	CHRONIC
ADUR_ATnc	10950	ADUR_IRPfr	63000
ADUR_ED	30	ADUR_IRPvg	175000
ADUR_EF	270	ADUR_Flp	0.25
ADUR_BW	70		

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table G-14a
Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm^2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	3.8E-01			3.8E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		4E-01	0E+00	0E+00	4E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-14b
Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	5.9E-02	3.2E-01	1.9E-02	-	-		-	1.6E-03	1.9E-03	3.5E-03	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		2E-03	2E-03	3E-03	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

CHR_ATC	25550	Exposure Duration	CHRONIC
CHR_ATnc	2190	CHR_IRPfr	69000
CHR_ED	6	CHR_IRPvg	81000
CHR_EF	270	CHR_Flp	0.25
CHR_BW	15		

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table G-14c
Subchronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	3.8E-02			3.8E-02	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		4E-02	0E+00	0E+00	4E-02	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-14d
Subchronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	5.9E-02	3.2E-01	1.9E-02	-	-		-	1.6E-04	1.9E-04	3.5E-04	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		2E-04	2E-04	3E-04	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

CHR_ATC	25550	CHR_IRPfr	69000
CHR_ATnc	2190	CHR_IRPvg	81000
CHR_ED	6	CHR_Flp	0.25
CHR_EF	270		
CHR_BW	15		

Exposure Duration SUBCHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table G-15a
Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	8.9E-02			8.9E-02	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		9E-02	0E+00	0E+00	9E-02	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:
ELCRo = (EPCgw × FIgw × IRgw × EFgw × ED × CSFo) / (BW × ATc)

HQo = (EPCgw × FIgw × IRgw × EFgw × ED) / (BW × ATnc × RfDo)

Table G-15b
Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	5.9E-02	3.2E-01	1.9E-02	-	-		-	2.2E-04	1.7E-04	3.9E-04	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		2E-04	2E-04	4E-04	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

INF_ATC	25550	INF_IRPfr	41850
INF_ATnc	365	INF_IRPvg	33750
INF_ED	1	INF_Flp	0.25
INF_EF	270		
INF_BW	6.75		

Exposure Duration SUBCHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table G-16

Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] (L/cm^2/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK: Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	1.2E-01			1.2E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		1E-01	0E+00	0E+00	1E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-17

Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm^2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	5.9E-02					-			-	-	1.2E-01			1.2E-01	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		1E-01	0E+00	0E+00	1E-01	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

CIo_ATC	25550	CIo_ETgwi	–
CIo_ATnc	9125	CIo_EvFgw	–
CIo_BW	70	CIo_FIgw	1
CIo_ED	25	CIo_IRgw	2
CIo_EFgw	250	CIo_Sagw	–
CIo_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-18

Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - Exposure Unit 2 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK: Route-Specific Risk Oral	Dermal [c]	Inhalation (trench air) [c]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal [c]	Inhalation (trench air) [c]	Calculated Hazard	Percent Total HI
Miscellaneous														
Sulfolane	5.9E-02		2.0E-07		-			-	-	1.1E-05			1.1E-05	100%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		1E-05	0E+00	0E+00	1E-05	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	mg/m^3:	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:

[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

Exposure Duration SUBCHRONIC

CST_ATC	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_Flgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Equations:

$ELCRo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-19a

Chronic Hazard Estimates for the Offsite Adult Resident Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	2.8E-02			2.8E-02	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		3E-02	0E+00	0E+00	3E-02	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

ADUR_ATC	25550	ADUR_ETgwi	–
ADUR_ATnc	10950	ADUR_EvFgw	–
ADUR_BW	70	ADUR_FIgw	1
ADUR_ED	30	ADUR_IRgw	2
ADUR_EFgw	350	ADUR_Sagw	–
ADUR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-19b
Chronic Hazard Estimates for the Offsite Adult Resident Ingesting Homegrown Produce - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.0E-02	3.2E-01	3.3E-03	-	-		-	5.4E-05	1.5E-04	2.1E-04	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		5E-05	2E-04	2E-04	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

		Exposure Duration	CHRONIC
ADUR_ATC	25550	ADUR_IRPfr	63000
ADUR_ATnc	10950	ADUR_IRPvg	175000
ADUR_ED	30	ADUR_Flp	0.25
ADUR_EF	270		
ADUR_BW	70		

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table G-20a

Chronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm^2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	6.5E-02			6.5E-02	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		7E-02	0E+00	0E+00	7E-02	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-20b
Chronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.0E-02	3.2E-01	3.3E-03	-	-		-	2.8E-04	3.3E-04	6.0E-04	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		3E-04	3E-04	6E-04	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

CHR_ATC	25550	CHR_IRPfr	69000
CHR_ATnc	2190	CHR_IRPvg	81000
CHR_ED	6	CHR_Flp	0.25
CHR_EF	270		
CHR_BW	15		

Exposure Duration CHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table G-20c

Subchronic Hazard Estimates for the Offsite Child Resident Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	6.5E-03			6.5E-03	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		7E-03	0E+00	0E+00	7E-03	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

CHR_ATC	25550	CHR_ETgwi	–
CHR_ATnc	2190	CHR_EvFgw	–
CHR_BW	15	CHR_FIgw	1
CHR_ED	6	CHR_IRgw	1
CHR_EFgw	350	CHR_Sagw	–
CHR_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-20d
Subchronic Hazard Estimates for the Offsite Child Resident Ingesting Homegrown Produce - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.0E-02	3.2E-01	3.3E-03	-	-		-	2.8E-05	3.3E-05	6.0E-05	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		3E-05	3E-05	6E-05	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

CHR_ATC	25550	CHR_IRPfr	69000
CHR_ATnc	2190	CHR_IRPvg	81000
CHR_ED	6	CHR_Flp	0.25
CHR_EF	270		
CHR_BW	15		

Exposure Duration SUBCHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table G-21a
Subchronic Hazard Estimates for the Offsite Infant Resident Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	1.5E-02			1.5E-02	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-02	0E+00	0E+00	2E-02	

Abbreviations:

-:	Not applicable	L/m³:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:
[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).
[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.
[c] Media evaluated separately.
[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

INF_ATC	25550	INF_ETgwi	–
INF_ATnc	365	INF_EvFgw	–
INF_BW	6.75	INF_FIgw	1
INF_ED	1	INF_IRgw	1.0546875
INF_EFgw	350	INF_Sagw	–
INF_EvTgw	–		

Exposure Duration SUBCHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-21b
Subchronic Hazard Estimates for the Offsite Infant Resident Ingesting Homegrown Produce - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario
Flint Hills North Pole Refinery
North Pole, Alaska

Constituent	EPCgw (mg/L) [b]	BCF (L/kg ww) [a]	EPCp (mg/kg ww) [a]	CANCER RISK Route-Specific Risk Ingestion (fruit)	CANCER RISK Route-Specific Risk Ingestion (vegetables)	CANCER RISK Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Ingestion (fruit)	NON-CANCER HAZARD Route-Specific Hazard Ingestion (vegetables)	NON-CANCER HAZARD Calculated Hazard	Percent Total HI
Miscellaneous											
Sulfolane	1.0E-02	3.2E-01	3.3E-03	-	-		-	3.7E-05	3.0E-05	6.8E-05	100%
Total Risk or Hazard				0E+00	0E+00	0E+00		4E-05	3E-05	7E-05	

Abbreviations:

-:	Not applicable	HI:	Hazard index (unitless)
ELCR:	Excess lifetime cancer risk (unitless)	L/kw ww:	Liter(s) per kilogram produce in wet weight
BCF:	Water-to-produce Bioconcentration Factor (L/kg ww)	mg/kw ww:	Milligram(s) per kilogram wet weight
EPCgw:	Exposure point concentration in groundwater (ug/L)	mg/L:	Milligram(s) per liter
EPCp:	Exposure point concentration in produce (mg/kg ww)		
HI:	Hazard index (unitless)	V:	Indicates the constituent is a volatile compound, as defined by USEPA

Notes:
[a] Modeled produce concentrations calculated from BCF derived as described in Section 3.
[b] Media evaluated separately.

Parameters (see Table 3-12b for definitions):

INF_ATC	25550	INF_IRPfr	41850
INF_ATnc	365	INF_IRPvg	33750
INF_ED	1	INF_Flp	0.25
INF_EF	270		
INF_BW	6.75		

Exposure Duration SUBCHRONIC

Equations:

ELCRp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED × CSF) / (1,000,000 × BW × ATC)

HIp = ([EPCgw × BCF] × [IRfr + IRvg] × Flp × EF × ED) / (1,000,000 × BW × ATnc × RfD)

Table G-22

Chronic Hazard Estimates for the Offsite Commercial/Industrial Indoor Worker Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] (L/cm^2/event)	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK: Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	2.0E-02			2.0E-02	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-02	0E+00	0E+00	2E-02	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

CI_ATC	25550	CI_ETgwi	–
CI_ATnc	9125	CI_EvFgw	–
CI_BW	70	CI_FIgw	1
CI_ED	25	CI_IRgw	2
CI_EFgw	250	CI_Sagw	–
CI_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-23

Chronic Hazard Estimates for the Offsite Commercial/Industrial Outdoor Worker Exposed to Groundwater - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m^3)	DA [b] L/cm^2/event	EPCdu (mg/m3)	EPCia (mg/m3) [c]	CANCER RISK: Route-Specific Risk Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD: Route-Specific Hazard Oral	Dermal [d]	Inhalation (domestic use) [d]	Calculated Hazard	Percent Total HI
Miscellaneous															
Sulfolane	1.0E-02					-			-	-	2.0E-02			2.0E-02	100%
Total Risk or Hazard						0E+00	0E+00	0E+00	0E+00		2E-02	0E+00	0E+00	2E-02	

Abbreviations:

-:	Not applicable	L/m^3:	Liter(s) per cubic meter
DA:	Dermal absorption factor (L/cm^2/event)	L/cm^2/event:	Liter(s) per cubic centimeter per event
ELCR:	Excess lifetime cancer risk (unitless)	mg/L:	Milligram(s) per liter
EPCdu:	Exposure point concentration in air during showering (mg/m^3)	mg/m^3:	Milligram(s) per cubic meter
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)	V:	Indicates the constituent is a volatile compound, as defined by USEPA
HI:	Hazard index (unitless)	VF:	Volatilization factor (L/m^3)
HQ:	Hazard quotient (unitless)	VOCs:	Volatile organic compounds

Notes:

[a] Andelman's value was used as the VF, from RAGS Part B (USEPA, 1991).

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Media evaluated separately.

[d] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

CIo_ATC	25550	CIo_ETgwi	–
CIo_ATnc	9125	CIo_EvFgw	–
CIo_BW	70	CIo_FIgw	1
CIo_ED	25	CIo_IRgw	2
CIo_EFgw	250	CIo_Sagw	–
CIo_EvTgw	–		

Exposure Duration CHRONIC

Equations:

$ELCRo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times FIgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

Table G-24

Subchronic Hazard Estimates for the Offsite Construction/Trench Worker Exposed to Groundwater in a Trench - Exposure Unit 3 - UCL COPC Concentrations

Human Health Risk Assessment - ARCADIS Scenario

Flint Hills North Pole Refinery

North Pole, Alaska

Constituent	EPCgw (mg/L)	VF [a] (L/m³)	DA [b] L/cm2/event	EPCta (mg/m3)	CANCER RISK Route-Specific Risk Oral	Dermal [c]	Inhalation (trench air) [c]	Calculated Risk	Percent Total ELCR	NON-CANCER HAZARD Route-Specific Hazard Oral	Dermal [c]	Inhalation (trench air) [c]	Calculated Hazard	Percent Total HI
Miscellaneous														
Sulfolane	1.0E-02		2.0E-07		-			-	-	1.8E-06			1.8E-06	100%
Total Risk or Hazard					0E+00	0E+00	0E+00	0E+00		2E-06	0E+00	0E+00	2E-06	

Abbreviations:

- :	Not applicable	mg/L:	Milligram(s) per liter
ELCR:	Excess lifetime cancer risk (unitless)	$mg/m^{3:}$	Milligram(s) per cubic meter
EPCta:	Exposure point concentration in trench air (mg/m^3)	V:	Indicates the constituent is a volatile compound, as defined by CalEPA (1994)
EPCia:	Exposure point concentration in indoor air (mg/m^3)	VF:	Volatilization factor (m^3/kg)
EPCgw:	Exposure point concentration in groundwater (mg/L)		
HI:	Hazard index (unitless)		
HQ:	Hazard quotient (unitless)		
L/m^3:	Liter(s) per cubic meter		

Notes:

[a] Calculated using default assumptions in the Virginia Department of Environmental Quality Trench Air Model for groundwater less than 15 feet.

[b] The dermal absorption factor (DA) was calculated using event time (EvTgw) as shown for this receptor below.

[c] Dermal and inhalation exposures are insignficant for sulfolane, as discussed in the RAWP (ARCADIS, 2011)

Parameters (see Table 3-12b for definitions):

Exposure Duration SUBCHRONIC

CST_ATc	25550	CST_ET	1
CST_ATnc	365	CST_EvTgw	1
CST_BW	70	CST_EvFgw	1
CST_ED	1	CST_Flgw	1
CST_EFgw	125	CST_IRinc_gw	0.0037
CST_EFtr	125	CST_SAgw	2230

Equations:

$ELCRo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED \times CSFo) / (BW \times ATc)$

$HQo = (EPCgw \times Flgw \times IRgw \times EFgw \times ED) / (BW \times ATnc \times RfDo)$

ARCADIS

Appendix H

Toxicity Profiles for Risk/Hazard Drivers and Assessment of Dose Response Information for Sulfolane

ARSENIC

The toxicity of arsenic depends upon its chemical form along with the route, dose, and duration of exposure. In general, arsenites (As^{+3}) are potentially more toxic than arsenates, soluble arsenic compounds are potentially more toxic than insoluble compounds, and inorganic arsenic compounds are potentially more toxic than organic derivatives (USEPA 1985).

Absorption from the gastrointestinal tract is dependent upon the solubility of the specific arsenic compound and the dose. Absorption from the respiratory tract is also dependent upon the specific arsenic compound, along with particle size.

Depending upon dose and exposure route, arsenic can be an irritant of the skin, mucous membranes, and the gastrointestinal tract. Acute toxicity from the ingestion of extremely high doses of arsenic may result in vomiting, diarrhea, convulsions, a severe drop in blood pressure, and cardiovascular effects. The lethal dose for humans is reported to be 1.0 to 2.6 milligrams per kilogram-body weight (mg/kg-bw) (Vallee et al. 1960). Acute toxicity from high level inhalation exposure to arsenic adsorbed to particulate matter may result in conjunctivitis and pharyngitis. Subchronic effects from high level exposures for many years include hyperpigmentation (melanosis), multiple arsenical keratoses, sensory-motor polyneuropathy, persistent chronic headache, lethargy, gastroenteritis, and mild iron deficiency anemia. Inhaled arsenic compounds have been reported to be associated with skin lesions, cardiovascular and respiratory effects, and peripheral neuropathy (Stokinger 1981; IARC 1980). Chronic oral exposure of humans to high levels of inorganic arsenic compounds over decades has been reported to cause skin lesions, peripheral vascular disease, and peripheral neuropathy (Silver and Wainman 1952). The incidence of blackfoot disease, a peripheral circulatory disease characterized by gangrene of the extremities, has reportedly been related to the presence of arsenic in the drinking water of residents of the southwest of Taiwan (Tseng 1977). The symptoms of chronic inhalation exposure to arsenic compounds are similar to those associated with chronic oral toxicity.

Oral LD_{50} values for trivalent arsenic vary from 15 to 293 mg/kg in rats and from 10-150 mg/kg in other test species (USEPA 1984). Chronic toxicity data from high level arsenic exposure to rats for their lifetime cannot be extrapolated to man as the rat is able to store this compound bound to hemoglobin in red blood cells (Lanz et al. 1950). This binding results in extremely slow excretion by rats compared to other species (Mealey et al. 1959). For this reason, dogs have been used to obtain experimental toxicity information. Studies of the subchronic oral toxicity of diets containing high levels of sodium arsenite or sodium arsenate in dogs report that arsenite is potentially more toxic than arsenate. The NOEL (no observed effect level) was reported to be 50 mg/kg-diet for both substances (Byron et al. 1967). Schroeder and Balassa (1967) studied the chronic oral toxicity of arsenic on growth and survival in mice. Ingestion of water containing As^{+3} at 5 mg/L over two years is reported to have resulted in decreased survival and reduced median life span in male and female mice. No information regarding chronic inhalation exposure of experimental animals to arsenic could be located in the available literature. Animal studies to test the teratogenic potential of arsenic at high dose levels have been performed. Diets containing up to 100 mg-arsenite/kg-

diet were reported to have had no effect on offspring (Kojima 1974). No data regarding the teratogenicity of inhaled arsenic could be found in the literature.

Nearly all results of gene mutation studies for arsenic (III) and arsenic (V) compounds have been negative. Arsenite and arsenate also have been inactive in gene-specific mutation assays in yeast and in cultured mammalian cells. In contrast, arsenic (III), arsenic (V), arsenite and arsenate have been found to result in chromosome aberrations and sister chromatid exchanges in cultured animal and human cells tested in vitro (ATSDR 1987). There is limited evidence that occupational exposure to arsenic may cause chromosome changes in humans (Beckman et al. 1977). Beckman et al. (1977) reported an increase in gaps, chromatid aberrations and chromosome aberrations from mine workers at a smelter in northern Sweden.

The majority of tests in which experimental animals were exposed orally to a variety of arsenic compounds produced negative results regarding carcinogenicity (Hueper and Payne 1962; Byron et al. 1967). A few studies have, however, reported tumorigenic effects of arsenic treatment (Schrauzer et al. 1978). Mixed results were reported in arsenic inhalation studies (Ishinishi et al. 1977; Ivankovic et al. 1979). Epidemiological studies conducted in the U.S. have failed to correlate the incidence of skin cancer with arsenic in drinking water (Morton et al. 1976; Goldsmith et al. 1972). A dose-response relationship between the occurrence of skin cancer and arsenic consumption in the drinking water of Taiwanese, however, was reported by Tseng et al. (1977). Arsenic exposure at high doses may produce a pattern of skin disorders, hyperpigmentation, and keratosis that may develop into basal or squamous cell carcinoma (USEPA 1985). Several epidemiological studies of workers occupationally exposed to high levels of arsenic over a working lifetime have reported a correlation between this exposure and mortality due to respiratory cancer (Higgins et al. 1982; Enterline and Marsh 1982; Brown and Chu 1983). Based upon epidemiological data, historically the USEPA has classified arsenic as Group A -Human Carcinogen.

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BENZENE

Benzene is a clear, volatile, highly flammable, aromatic hydrocarbon which exists naturally and is produced by volcanoes and forest fires. Benzene is also a very common industrial solvent, produced from petroleum. It is used as a solvent for fats, inks, paints, plastics, rubber, in the extraction of oils from seeds and nuts, in photogravure printing, as a chemical intermediate and in the manufacture of detergents, explosives, pharmaceuticals and dyestuffs. It is also a component of gasoline and other petroleum-based fuels. Exposure to benzene can occur via inhalation, ingestion, especially of contaminated drinking water, and dermal contact (as in contact with liquid benzene found in gasoline) (Sittig 1981; ATSDR, 1989).

Benzene is readily absorbed through ingestion, moderately absorbed through inhalation and poorly absorbed through intact skin. Once in the bloodstream, benzene is distributed throughout the body, with the concentration in any one compartment dependent on the degree of perfusion of tissues by blood. Since benzene is lipid-soluble, it accumulates in fat, but the rate of accumulation is slow since fat is poorly perfused. The metabolites of benzene are responsible for its toxic effects. These include phenol (which is either formed via an unstable benzene oxide precursor or directly from benzene), catechol, hydroquinone and conjugated phenolic compounds. The primary site of benzene metabolism is the liver via the cytochrome P450 mixed function oxidase system. Some benzene metabolism may also occur in the bone marrow via the same enzyme system. Benzene is excreted either unchanged from the lungs or as metabolites in the urine (ATSDR, 1989).

Benzene targets its effects on the hemopoietic, immune and nervous systems (ATSDR, 1989). Exposure to very high levels of benzene has produced irritation of the skin, eyes and upper respiratory tract. Acute exposure has produced central nervous system depression, headache, dizziness, nausea, convulsions, coma and death at extremely high concentrations (Sittig, 1981). Certain health effects in humans have been reported starting as low as 50 ppm via inhalation. Twenty-five ppm for six hours had no obvious effects though benzene was detected in blood (Sandmeyer, 1981). Chronic exposure to high levels of benzene can produce blood changes involving an initial increase in levels of erythrocytes, leukocytes and thrombocytes, followed by aplastic anemia indicated by anemia, leukopenia and thrombocytopenia (Sittig, 1981).

The following effects have been produced experimentally in laboratory animals, following high level exposure to benzene: decreased leukocyte and/or erythrocyte counts, reduction in cellular immunity and bone marrow depression (reduced number of granulopoietic stem cells). Animal studies do not indicate that benzene is teratogenic, but the following fetotoxic effects have been found when doses are sufficiently high: reduced fetal weight, altered fetal hematopoiesis, fetal skeletal variations and increased resorptions in pregnant exposed animals. In addition, benzene has produced histopathological changes in ovaries and testes of test animals (ATSDR 1989).

Benzene and its metabolites have been shown to be mutagenic in a number of *in vitro* and *in vivo* studies. Genotoxic effects produced experimentally include structural and numerical chromosome aberrations in humans, animals and cell cultures, and sister chromatid exchanges and micronuclei in in vivo animal studies. Benzene exposure has been found to produce an increase in the number of chromosome aberrations associated with myelotoxicity (Sittig 1981). In addition, sperm head

abnormalities, inhibition of DNA and RNA synthesis, DNA binding and interference with cell cycle progression have been shown in in vitro studies (ATSDR 1989). The epidemiologic data indicate that benzene may be leukemogenic. The evidence is most convincing for acute myelogenous and acute erythroleukemia, although a correlation has also been reported for chronic leukemia. Benzene has been designated a group A human carcinogen (leukemogen) by inhalation. Although data are insufficient to validate the carcinogenicity of benzene via ingestion, it would not be unreasonable to assume that benzene is carcinogenic via this route as well if present in sufficient quantities. The carcinogenicity of benzene via dermal exposure is considered to be lower since benzene is absorbed poorly through the skin (ATSDR 1989).

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NAPHTHALENE

Naphthalene is a naturally occurring constituent of petroleum and other natural organic materials, and enters the air during the combustion of gasoline, oils, wood, coal, and other fuels. It is also released from cigarette smoke, from household products such as mothballs, and from industrial processes that use it as a reagent in the production of a variety of other chemicals and polyvinyl chloride (ATSDR 2005). Exposure to naphthalene can occur via inhalation, ingestion of drinking water, and dermal contact with materials (e.g., moth balls or materials treated with moth balls) containing naphthalene.

Naphthalene is assumed to be readily absorbed through inhalation although no human or animal studies have been located measuring the rate of absorption in either humans or animals. It is presumed that naphthalene moves across the alveolar membrane by passive diffusion through the lipophilic matrix (ATSDR 2005). From studies of polynuclear aromatic hydrocarbons including naphthalene, naphthalene is moderately to poorly absorbed into the blood stream once ingested or absorbed through intact skin, although the level of dermal absorption depends upon the nature of the soil type. Once naphthalene is absorbed, a complex metabolic pathway occurs via the P450 mixed function oxidase enzyme system, with multiple competing pathways leading to the formation of several reactive metabolites (e.g., 1,2-naphthalene oxide, 1,2-naphthoquinone, and 1,4-naphthoquinone) and an array of conjugated and nonconjugated metabolites that are excreted predominantly in the urine. (ATSDR 2005). Conjugation of the reactive metabolites is viewed as a detoxifying mechanism for the reactive metabolites. There are significant differences among different animal species following acute and chronic inhalation exposures to naphthalene (with rats more susceptible than either mice or hamsters) suggesting species differences in relevant metabolic pathways (ATSDR 2005), in addition to anatomical and physiological differences (Buckpitt 2011; Rhomberg 2010; Piccirello 2011). No studies were identified that evaluated the distribution of naphthalene following inhalation exposure. Once in the bloodstream, naphthalene is distributed throughout the body, with concentrations in any one compartment dependent upon the dose and degree of blood perfusion within that tissue. Following oral exposure, the liver is expected to be the principal site of metabolism (ATSDR 2005). No studies were located that documented excretion in humans or animals after inhalation exposure. Following oral exposures, naphthalene metabolites are primarily excreted in urine with unabsorbed naphthalene representing a minor excretion pathway (ATSDR 2005).

Although ingestion of naphthalene-containing mothballs has resulted in no ill effects in some cases (Sandmeyer 1981), hemolytic anemia and cataracts have been observed in humans following accidental or intentional ingestion and inhalation of extremely high doses of naphthalene (acute exposure). However, information is not available regarding dose-response relationships for these effects in humans with acute, subchronic, or chronic exposure by any route (USEPA 2012). The hemolytic anemia subsequent to extremely high level exposure is associated with decreased hemoglobin, hematocrit and erythrocyte values, increased reticulocyte counts, presence of Heinz bodies, and increased serum bilirubin levels, and preferentially among individuals having a congenital deficiency of erythrocyte glucose-6-phosphate dehydrogenase. Other reported effects from acute exposure to high levels of

naphthalene include gastrointestinal disorders (nausea, vomiting, abdominal pain, and diarrhea); renal effects; neurological effects (confusion, listlessness, lethargy, vertigo, muscle twitching, convulsions, decreased responses to painful stimuli, cerebral edema, and coma); hepatic effects (jaundice, hepatomegaly, and elevated serum enzyme levels); and ocular effects (restricted visual fields, optic atrophy, and bilateral cataracts). Hemolytic anemia has also been noted in infants born to pregnant women who ingested high levels of naphthalene during the last trimester of pregnancy as mothballs intentional "sniffing" of mothballs (Anziulewicz et al. 1959; Zinkham and Childs 1958; as cited in RAIS (ORNL 2012)).

Among animal studies in which the test species are exposed to high concentrations in a laboratory setting via inhalation, rats exposed to 78 ppm naphthalene for 4 hours exhibited no clinical signs of toxicity during or 14 days after exposure (Fait and Nachreiner 1985; as cited in RAIS (ORNL 2012)). Animal inhalation studies are restricted to three studies of mice: a 2-year study (National Toxicology Program [NTP] 1992), a 6-month study (Adkins et al. 1986), and a 4-hour study (Buckpitt 1982) (as cited in USEPA 2012). Results from the chronic study, supported by the subchronic and acute studies, identify nasal and pulmonary injuries as critical effects from chronic inhalation exposure to naphthalene; effects in other organs or tissues were not found. Incidence data for male and female mice with hyperplasia of the nasal respiratory epithelium, metaplasia of the nasal olfactory epithelium, and chronic pulmonary inflammation clearly show that the nose is more sensitive than the lung to chronic inhalation exposure to high levels of naphthalene.

There are no adequate studies or reports on the carcinogenicity of naphthalene in humans following oral, dermal or inhalation exposures (USEPA 2012).

The potential for naphthalene to induce carcinogenic effects in laboratory animals was tested by the NTP in two-year inhalation studies in B6C3F1 mice (NTP 1992) and F344/N rats (NTP 2000). Increased incidences of lung tumors (primarily alveolar/bronchiolar adenomas) in female mice and nasal tumors (primarily olfactory epithelial neuroblastomas and respiratory epithelial adenomas) in male and female rats were observed during these studies. These naphthalene-induced neoplastic lesions found in mice (lung adenomas) and rats (nose respiratory epithelial adenomas and olfactory epithelial neuroblastomas) are not caused by a genotoxic mode of action. Results from genotoxicity tests for naphthalene have been predominately negative.

Based on these results, the International Agency for Research on Cancer (IARC) classified naphthalene as a 2B carcinogen (“possibly carcinogenic to humans”) (IARC 2002); NTP listed naphthalene as “reasonably anticipated to be a human carcinogen” (NTP 2004); and California Environmental Protection Agency (CalEPA) developed an inhalation Unit Risk Factor (URF) for use in human health risk assessments for waste sites under state control (CalEPA 2009).

In an unpublished preliminary assessment, the USEPA proposed an inhalation unit risk (IUR) of 0.1 $(mg/m^3)^{-1}$ (USEPA 2004) based on the results of the NTP study in which naphthalene exposure corresponded to increases in the incidence of olfactory epithelial neuroblastomas and respiratory epithelial adenomas in male rats (NTP 2000). USEPA also proposed an IUR of 0.054 $(mg/m^3)^{-1}$ based on olfactory epithelial neuroblastomas in female rats. USEPA later

withdrew both IURs. Naphthalene is currently being re-evaluated for USEPA's Integrated Risk Information System ([IRIS] 2012).

Using the same NTP study, California's Office of Environmental Health Hazard Assessment (OEHHA) has derived an IUR value for estimating the cancer risk associated with inhalation exposures to naphthalene under the state Air Toxics Hot Spots and TAC programs (OEHHA 2007). OEHHA derived the IUR value for naphthalene from incidence data of nasal respiratory epithelial adenoma and nasal olfactory epithelial neuroblastoma in male rats in the NTP study (NTP 2000). Naphthalene is not mutagenic in animals and the observed carcinogenicity is due to a non-genotoxic mechanism (USEPA 2012). The evidence of carcinogenicity from the NTP study is only in one species (rats with no unusual degree of tumors) and not from multiple species.

Current scientific research demonstrates that the URF derived by OHEEA based on the NTP rodent studies is not relevant to human health risk assessment. Since the listing of naphthalene as a *possible or reasonably anticipated* carcinogen by IARC and NTP, numerous investigators have raised strong concerns regarding the relevance of the rodent inhalation cancer data to humans.

One set of concerns revolves around the well-documented anatomical and physiological differences between the upper airways of rodents and humans and evidence that suggests that human are less, not more, sensitive than rodents to health effects from inhaled naphthalene. Considerable recent research has been dedicated to elucidating the mode of action (MoA) by which naphthalene could potentially cause cancer in humans, based on comparisons with metabolic and genetic processes in rodents and non-human primates.

While not reviewed comprehensively here, much of that research demonstrates a lack of species concordance between rodents and humans with respect to a MoA for naphthalene. For example, with recent research, Buckpitt et al. (2011) found 10- to 50-fold lower target tissue metabolism of naphthalene in monkey compared to rat olfactory epithelium, and weight-of-evidence reviews by Rhomberg et al. (2010) and Piccirillo et al. (2011) found no clear indications that any currently hypothesized MoA for naphthalene in rodents is relevant to humans.

Another set of concerns revolves around the high doses of naphthalene employed in the NTP rodent studies. An expert panel at the Naphthalene State-of-the-Science Symposium (NS^3) charged with reviewing naphthalene metabolism in relation to tissues with elevated tumor incidence in the NTP rodent studies concluded that linear extrapolation from tumor induction rates in rodents chronically exposed to high, cytotoxic naphthalene concentrations did not meaningfully predict tumor induction rates from environmental, non-cytotoxic concentrations (Bogen et al. 2008).

Another expert panel concluded from signs of inflammation indicating extensive cytotoxicity that the maximum tolerated dose (MTD) was exceeded in both doses in both sexes in the NTP (2000) rat bioassay (North et al. 2008). According to the National Research Council (1993), studies executed at doses that exceed the MTD are inappropriate for cancer risk assessment.

Thus, the NTP rodent studies are not appropriate to use as a basis for any cancer risk assessment activities.

In addition, the USEPA's Office of Prevention, Pesticides and Toxic Substances reviewed these same data when considering the re-registration of naphthalene mothballs and concluded that there was inadequate evidence to evaluate naphthalene as a human carcinogen (USEPA 2008).

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SULFOLANE

Introduction

Sulfolane, tetrahydrothiophene-1,1-dioxide, is a man-made industrial solvent commonly used in gas production and oil refining (Alaska Department of Health and Social Services [ADHSS] 2012). The sulfur-oxygen double bond is highly polar, which makes it very water soluble. The presence of the four-carbon ring allows for some non-polar stability. These properties make sulfolane miscible in both water and hydrocarbons, which gives it desirable properties as a solvent for purifying hydrocarbon mixtures (ADHSS 2012).

Sulfolane is absorbed via the oral route. However, is not readily absorbed via the dermal and inhalation routes. Animal studies have shown that sulfolane is not readily absorbed through human skin because of its low permeability (Brown et al. 1966) and is not expected to pose a significant risk via an inhalation exposure route due to its low volatility (Andersen et al. 1977). Brown et al. (1966) studied the skin and eye irritant and skin sensitizing properties of acute exposures to sulfolane on two animal species. It was concluded that sulfolane did not irritate or sensitize the skins of guinea pigs or rabbits and, undiluted, was only very mildly irritating on the eyes of rabbits. Andersen et al. (1977) conducted acute and subacute investigations of the inhalation toxicity of sulfolane on four animal species including monkey, dog, guinea pig and rat. A no observed adverse effect level (NOAEL) of 20 mg sulfolane per cubic meter (m^3) was reported. The authors also concluded that airborne concentrations of sulfolane as high as those investigated are unlikely to be encountered on any but an emergency basis. They reported that sulfolane has a relatively low vapor pressure of about 0.13 millimeters mercury at 32^o Celsius and that only unusual conditions would produce extensive release of aerosolized sulfolane. They further noted that if it is handled at room temperature in an area with proper ventilation, sulfolane should not be regarded as posing any unusual hazard.

There are three laboratory animal studies that have been used by various parties to derive toxicological reference values for sulfolane. Zhu et al. (1987) was a six-page report published in a Chinese journal entitled Huaxi yike daxue xuebao, (Journal of West China University of Medical Sciences). In this study, a series of experiments were performed. Acute, subchronic (90-day), and chronic (6-month) toxicity testing was performed via the oral route of exposure in mice, white rats, and guinea pigs. Zhu et al. (1987) also performed a developmental toxicity study in mice and several genotoxicity tests. Huntingdon Life Sciences (2001) was a GLP-compliant study in which sulfolane was administered to CD rats (10/sex/group) in drinking water at concentrations of 0, 25, 100, 400, or 1600 mg/L for 13 weeks. All animals were examined for individual signs of general health, body weights, food and water consumption, ophthalmoscopy, functional observation battery, hematology, blood chemistry, organ weights, macropathology, and hisopathology. The Ministry of Health and Welfare Japan (MHWJ, 1999) was a 50-day oral gavage study in Crj:CD(S-D) rats as summarized in Organization for Economic Co-operation and Development ([OECD] 2004). These studies are evaluated below in the context of evaluating existing Reference Doses (RfDs) and similar toxicological reference criteria and deriving the alternative scientifically defensible RfDs from the scientific literature.

These studies have been evaluated in various efforts to set toxicologic criteria by U.S and Canadian entities and by ATSDR and form the basis for the EPA's PPRTV. They are also considered in the attached Assessment of Dose Response for Sufolane by Dr. Brian Magee of Arcadis.

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1,3,5-TRIMETHYLBENZENE

1,3,5-Trimethylbenzene,or mesitylene, is a colorless liquid with a peculiar odor used in the manufacturing of dyes, as an ultraviolet oxidation stabilizer of plastics, and as a gasoline additive.

There is no information regarding the toxic effects in humans following oral exposure. A no observed adverse effect level (NOAEL) of 200 mg 1,3-5-trimethylbenzene per kilogram body weight per day (mg/kg-d) was used as the basis of a chronic oral screening value and a subchronic oral screening value (USEPA 2009). USEPA notes that although the single laboratory study was comprehensive for systemic toxicity, only one species was tested (rats), and studies evaluating oral neurotoxicity, developmental and reproductive toxicity are lacking. The observed effects in the oral rat studies include decreased body weight, blood chemistry changes (including changes in cholesterol levels), and increases in relative liver weight.

From a limited occupational study in which workers were exposed to workplace air containing a high concentration of a mixture of trimethylbenzene isomers (reported to include more than 30% 1,3,5-trimethylbenzene and more than 50% 1,2,4-trimethylbenzene), workers reported CNS symptoms (vertigo, headaches, and drowsiness) which were reversible, chronic asthma-like bronchitis, hyperchromic anemia, and alterations in blood clotting (Batting 1958; as cited in PPRTV documentation). In another health effects study in healthy humans, no CNS effects or eye, nose or airway irritations were reported following acute inhalation exposures to 1,3,5-trimethylbenznene (Jamberg 1996). This study indicated a high respiratory uptake (>60% at 25 ppm) and moderately rapid elimination (~1 L/hr-kg). A large volume of distribution (~39 L/kg) and long terminal half-life in blood (120 hours) implied extensive accumulation of 1,3,5-trimethylbenzene in adipose tissue. The primary metabolite reported in urine was 3,5-dimethylbenzoic acid (USEPA 2009).

Potential effects reported in several animal studies where 1,3,5-trimenthylbenzene was present in air at high levels either alone or as a mixture of trimethylbenzene isomers include CNS alterations (including impaired learning and memory), decreased body weight, hematological effects, and fatty changes in the liver and kidneys.

The data from limited developmental toxicity studies in laboratory animals exposed to high levels of 1,3,5-trimethylbenzene in air indicate reductions in maternal and fetal body-weight (Saillenfait, 2005).

Limited genotoxicity data suggest that 1,3,5-trimethylbenzene is not mutagenic but may be clastogenic. 1,3,5-Trimethylbenzene did not induce reverse mutations in *in vitro* assays (Janik-Spiechowicz et al. 1998; Nohmi et al. 1985; as cited in PPRTV documentation) and was negative in an *in vivo* assay and weakly positive at the middle and high dose levels in sister-chromatid exchange. In accordance with USEPA cancer guidelines (USEPA 2005), the available data for 1,3,5-trimethylbenzene are characterized as “Inadequate Information to Assess Carcinogenic Potential (USEPA 2009).

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XYLENES

A xylenes mixture is a colorless liquid with a sweet odor and a high degree of lipid solubility. There are three isomers of xylenes: meta, ortho- and para-xylene (m-, o-, and p-xylenes, respectively). The term “total xylenes” is used in reference to a mixture of the three possible isomers in any proportions, although USEPA notes that m-xylene is generally the predominant isomer in commercial mixtures (USEPA 2012). Xylenes are commonly used as industrial solvents, as components of paints, varnishes, cleaners, degreasers, and gasoline, and as chemical intermediates in the manufacture of other chemicals, plastics, and synthetic fibers. Xylenes are volatile molecules and therefore evaporate quickly. They are also flammable and may pose a fire hazard if improperly handled (ATSDR 2007).

Xylenes are absorbed following oral, dermal, or inhalation exposures. They can be stored in adipose tissue and areeliminated in the urine. The biotransformation of xylene in humans proceeds primarily by the oxidation of a side-chain methyl group by microsomal enzymes (mixed function oxidases) in the liver to yield toluic acids. Toluic acids conjugate with glycine to form conjugated toluic acids that are excreted into the urine (Astrand et al. 1978; Norstrom et al. 1989; Ogata et al. 1970, 1979; Riihimaki et al. 1979a; Sedivec and Flek 1976b; Senczuk and Orlowski 1978 as cited in ATSDR, 2007). This metabolic pathway accounts for almost all of the absorbed dose of xylenes, regardless of the isomers, route of administration, administered dose, or duration of exposure.

High levels of exposure to xylenes for short or long periods can cause headaches, lack of muscle coordination, dizziness, confusion, and changes in the sense of balance. Exposure of people to high levels of xylenes for short periods can also cause irritation of the skin, eyes, nose, and throat; difficulty in breathing; problems with the lungs; delayed reaction time; memory difficulties; stomach discomfort; and possibly changes in the liver and kidneys. It can cause unconsciousness and even death at very high levels.

Human exposure to xylenes vapor by the inhalation route may cause eye (Carpenter et al. 1975), nose, and throat (ATSDR 2007) irritation, and contact with liquid may result in dermatitis (Sittig, 1985). Chronic occupational exposure to xylenes has been associated with headaches, chest pain, electrocardiographic abnormalities, dyspnea, cyanosis of hands, fever, leukopenia, malaise, impaired lung function, and confusion (Hipolito 1980). Reversible symptoms of neurological impairment and irritation of the eyes and throat are well-known health hazards from acute inhalation exposure to xylenes. In general, these acute effects are expected to involve reversible molecular interactions of the solvent itself (not metabolites) with membranes of the affected tissues, including neuronal membranes, and are most pronounced at high exposure levels in excess of 1,000 ppm. At lower concentrations, more subtle effects may occur. Human volunteers exposed under controlled conditions to xylenes concentrations in the range of 200-400 ppm for short time periods (15 minutes to 4 hours) have reported symptoms of irritation (e.g., watering eyes and sore throat) or neurological impairment (e.g., mild nausea, headache) (Carpenter et al. 1975; Gamberale et al. 1978; as cited in Integrated Risk Information System (IRIS); USEPA 2012).

Long-term gavage studies with mixed xylenes in laboratory animals resulted in decreased body weight gain in male rats given 500 mg/kg/day and hyperactivity in male and female mice given 1,000 mg/kg/day (NTP 1986). A chronic oral reference dose (RfD) of 0.2 mg/kg/day for mixed xylenes was calculated from a no-observed-adverse-effect level (NOAEL) of 250 mg/kg/day derived from a chronic gavage study with rats (USEPA 2012). The critical effects were decreased body weight and increased mortality (males).

A chronic reference concentration (RfC) of 0.1 mg/m^3 was derived from a NOAEL of 2 mg/m^3 from a male rat inhalation study where m-xylene isomer was administered separately and in a mixture with toluene over 6 hours per day 5 days per week over a 3-month period. The critical effects were impaired motor coordination (Korsak et al. 1994; as cited in IRIS). The animal inhalation exposure database contains no chronic toxicity studies, but there are a number of subchronic toxicity studies (of which several focused on neurological endpoints), a one-generation reproduction study in rats, and several developmental toxicity studies, some of which evaluated offspring for performance in neurobehavioral tests. Subchronic toxicity assays in animals have not found consistent evidence for other noncancer effects, such as changes in body weight or in hepatic, hematologic, or renal toxicity endpoints, following exposure to concentrations of xylenes as high as 800-1,000 ppm for 6 hours per day, 5 days per week (e.g., Carpenter et al. 1975; Jenkins et al. 1970; Korsak et al. 1992, 1994; as cited in IRIS, USEPA 2012).

Data are inadequate for an assessment of the carcinogenic potential of xylenes. Adequate human data on the carcinogenicity of xylenes are not available, and the available animal data are inconclusive as to the ability of xylenes to cause a carcinogenic response. Evaluations of the genotoxic effects of xylenes have consistently given negative results.

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MEMO

To:
Toxicology Excellence in Risk Assessment
Sulfolane Peer Review Meeting

Copies:

From:
Brian Magee, Ph.D.
Vice President, Principal Toxicologist

Date:
September 8, 2014

Subject:
Response to Comments Made in Gradient's Review and Verification of Existing Sulfolane Dose-Response Assessments

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This memorandum responds to comments made in *Review and Verification of Existing Sulfolane Dose-Response Assessments* (2014), prepared by Gradient Corporation (Gradient) for the Alaska Department of Environmental Conservation (ADEC), in regards to ARCADIS' derivation of an oral reference dose for sulfolane. The information in this memorandum clarifies activities performed by ARCADIS (Magee, 2012) during its independent derivation of an oral reference dose (RfD_O) for sulfolane in support of developing a groundwater cleanup level included in the 2012 Revised Draft Human Health Risk Assessment (HHRA) (copy attached) for the North Pole Refinery, North Pole, Alaska.

COMMENT 1: In reference to Magee (2012), Gradient (2014) states on page 5 that:

> "*ARCADIS did not report any alternative BMD analyses, rather provided only a critique of existing analyses*."

RESPONSE 1: ARCADIS' study of the human health impacts of sulfolane related to the North Pole Refinery Site is described in the 2012 Revised Draft HHRA in which it independently identified primary toxicology studies with relevant data, evaluated the strength of each data set, and performed Benchmark $Dose_{Low}$ (BMDL) analyses using the biological effects data reported in the Huntingdon Life Sciences (2001) study and adhering to EPA guidance (1995, 2000, 2012). The information presented in Magee (2012) relied on dose-response analyses that were independently performed by ARCADIS in June, 2010 employing EPA's Benchmark Dose Software (BMDS) (v 2.1.1) software. This modeling resulted in four models that adequately fit the white blood cell response data (Exponential (M2), Exponential (M4), Linear, and Power) and that, when averaged, yielded a BMDL of 11.64 mg/kg-d. The ARCADIS approach differed modestly from the approach taken by Thompson et al. (2013) and Gradient (2014), but produced a comparable BMDL estimate. The ARCADIS BMDL analyses used to develop the position presented in Magee (2012) are alternative analyses to those described by Gradient (2014) and Thompson et al. (2013).

Taken together, the results indicate that comparable BMDL estimates have been reached by different groups of researchers, using different versions of EPA's modeling software and assumptions.

COMMENT 2: In reference to Magee (2012), Gradient states the following on page 31:

> *"We note that there is a discrepancy in the discussion of model averaging by Magee (2012). On page 7, it states:*
>
> > *the white blood cell data using historical controls provided BMDLs ranging from 5.54 to 16.12 mg/kg-day, and all **five models [emphasis added [by Gradient]]** (exponential M2, exponential M4, linear, power and polynomial) gave identical homogeneity variance p-values, goodness of fit p-values, and AIC values. Further, even though **all four models [emphasis added [by Gradient]]** met the scaled residual criterion of absolute value <2, the scaled residuals for the linear, power, and polynomial models showed a slightly better fit to the data than the two exponential models (M2 and M4)…"*

RESPONSE 2: We agree that there is a discrepancy between the two bolded sections of text. There is a typographical error in Magee (2012) when reporting the results of ATSDR (2011). Both sections of bolded text identified by Gradient (2014) should state "five models" when referring to the ATSDR (2011) results. In Magee (2012), ARCADIS confirmed that the ATSDR (2011) identified five models that adequately fit the HLS (2011) data: Exponential (M2 and M4), Linear, Power, and Polynomial. Results associated with the polynomial and power models were not presented in ATSDR's Tables B-4, B-5, B-5, and B-7, because the results were identical to those obtained using the linear model.

COMMENT 3*:* In reference to Magee (2012), Gradient states the following on page 31:

> *"ARCADIS verified the white blood cell benchmark dose modeling of ToxStrategies 2011 [sic], specifically, the female rat BMDL values for the white blood cell decrements using the historical control variance are 8.78, 5.55, 16.12 and 16.12 mg/kg-day, for each of 4 BMD model types, with an average BMDL of 11.64 mg/kg-day. All models are acceptable fits to the experimental data, and the AIC values for the four models are identical. Thus, the USEPA's default averaging approach is appropriate for setting a Point of Departure. (Magee, 2012).*
>
> *It appears from this discussion that there may have been an error in the average provided for the WBC counts. As summarized in Table 3.13, there are indeed five models that provided adequate fits to the log-transformed WBC data (exponential M2, exponential M4, linear, power and polynomial). Thus, the average of the five BMDLs (16.12, 16.12, 16.12, 5.54, and 8.78 mg/kg-day) would be 12.54 mg/kg-day instead of 11.64, as cited above.*"

RESPONSE 3: It is correct that Magee (2012) determined that the polynomial model did not adequately fit the HLS study's white blood cell count data (2001). As a result, the average BMDL was calculated using output from the four models that adequately fit the data (Exponential (M2), Exponential (M4), Linear, Power). This resulted in an average BMDL of 11.64 mg/kg-day. The source of the discrepancy between Magee (2012) and Gradient (2014) is related to the way that restrictions were applied to polynomial coefficients (β) during parameterization of the BMD model.

The BMD software used by Magee (2012) (EPA BMDS v 2.1.1) and Gradient (2014) (EPA BMDS v 2.5) allow users to choose whether or not to apply restrictions to polynomial model β's, specifically restrictions to either positive or negative values. However, the software version used by Magee (2012) (BMDS (v 2.1.1)) requires users to manually select whether or not to restrict the β's and, if restricted, whether to restrict the values to positive values or negative values. Magee (2012) did not apply restrictions to β's during modeling. When the polynomial model was then evaluated to determine if it fit the data, Magee (2012) found that the polynomial model did not provide an adequate global goodness-of-fit (p-value = 0.078). In contrast, Gradient (2014) employed BMDS (v 2.5) in combination with the BMD Wizard (v 1.9). This version of the BMD Wizard restricts β's to non-positive values by default. Gradient (2014) did not indicate whether it adjusted any of the default settings of the BMD Wizard, so ARCADIS assumes that Gradient (2014) used the default settings. Under the default modeling conditions, Gradient (2014) found that polynomial models did adequately fit the white blood cell count data.

EPA guidance (2000) does not provide any recommendations for applying restrictions to polynomial model β's. EPA (2012) recommends usually restricting polynomial β's to ≤ 0 for decreasing response data "to ensure monotonic curves." When Magee (2012) fit polynomial models parameterized with non-restricted β's to the white blood cell count data, he found that the model produced a monotonic dose-response curve. Thus, Magee (2012) did not find any evidence to require restricting β's to non-positive values.

COMMENT 4: In reference to Magee (2012), Gradient states on Page 36, Table 4.2 that:

> "*ARCADIS relied upon BMDL estimates from Thompson et al. (2013) and averaged the BMDLs from four viable models (using historical control data). (Note this is equivalent to Approach 3 from Table 4.1, however the average was calculated incorrectly and should equal 12.54 mg/kg-day)*."

RESPONSE 4: As noted above, ARCADIS independently calculated BMDLs using the biological effects data reported in the Huntingdon Life Sciences (2001) study in combination with EPA BMD guidance (1995, 2000, 2012). The information presented in Magee (2012) relied on dose-response analyses that were performed in June, 2010 using EPA's BMDS (v 2.1.1) software. It is correct that Magee (2012) determined that the polynomial model did not fit the data, and as a result the average BMDL was calculated based on the output from the four models that did adequately fit the data (Exponential (M2), Exponential (M4), Linear, and Power). This approach resulted in an average BMDL of 11.64 mg/kg-day. However, information in Tables 3.4 and 4.2 of Gradient's report (2014) indicates that polynomial models, in addition to the aforementioned models, also adequately fit the female rat white blood cell count data (HLS, 2001). The source of the discrepancy is related to the way that restrictions were applied to

polynomial coefficients (β) during parameterization of the dose-response model and is addressed in ARCADIS' response to comment 3. ARCADIS did not average the data incorrectly, but rather properly calculated an average BMDL using EPA guidance with EPA software available at the time. Based on this modeling with version 2.1.1 of EPA's BMD software, ARCADIS' results differ modestly from the approach taken by Gradient (2014) and Thompson et al. (2013).

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William H. Farland, PhD, ATS
September 8, 2014

Comments Provided for the Independent Peer Review of Established Reference Doses (RfDs) for Sulfolane

Coupling of Exposure Scenarios to RfD-like Values for Sulfolane

Development of RfD-like values is carried out for a variety of purposes. Frequently, these values are coupled with exposure scenarios to set acceptable or tolerable ("safe") levels to be used in public health protection or environmental regulation and/or remediation, e.g., establishing safe drinking water levels. Data-derived insights regarding relative acute versus chronic toxicity or age-related susceptibility, discussed in the course of the RfD development process, can be particularly useful for informing subsequent decisions regarding the choice of exposure parameters to apply in describing public health protective environmental levels. Data that have bearing on the choice of exposure parameters should be explicitly discussed and noted in the development of the RfD-like value. In my opinion, the available toxicity data base for sulfolane supports neither a concern for irreversible effects of early exposures nor age-specific sensitivity of children at RfD-like levels of exposure. Decision-makers should have the benefit of these toxicology-based insights when choosing to use more or less conservative approaches for coupling exposure scenarios with RfD-like values. Site-specific decisions ultimately determine how the use of toxicity data and exposure parameters will impact remediation goals.

A variety of approaches have been taken to couple exposure scenarios to RfD-like values when setting safe drinking water levels. These range from the use of the chronic RfD-like value (in mg/kg/day) converted to the equivalent of ppb in water, assuming consumption of 2 liters of water per day by a 70 kg human to set a drinking water equivalent level (DWEL), to the application of shorter (acute or subchronic) duration RfD-like values coupled with lower body weights and lower water consumption values to represent exposure scenarios for infants or children for a portion of their lifespan. The DWEL assumes that some fraction of the exposure will be coming through the drinking water route. The recent Health Canada (2014) "Drinking Water Guidance Value for Sulfolane" provides another example of such an approach.

As I have discussed previously[1], the use of an adult body weight and water consumption level has its basis in USEPA Drinking Water Standards and Health Advisories (HA) (USEPA, 2011). In this document a "Lifetime Health Advisory" is defined as "the concentration of a chemical in drinking water that is not expected to cause any adverse non-carcinogenic effects for a lifetime of exposure. The Lifetime HA is based on exposure of a 70-kg adult consuming 2 liters of water per day." One day or ten day health advisories use different assumptions regarding acute responses and a body weight of 10 kg and 1 liter a day consumption to protect infants for short durations of exposure when their body weight and consumption patterns could result in higher relative exposures. However, the assumption is that these short duration, higher exposure concerns are adequately accounted for by use of chronic RfD-like values for longer term (lifetime) exposures. Studies of "community water" consumption support these default values of 2 liters for lifetime exposure and 1 liter for infants' and children's exposure as representing the 80-90th percentile of the population values with mean consumption values being closer to half these values. It is considered fully protective of health to combine a chronic RfD-like value, which by definition is protective against appreciable risk for a

[1] Sulfolane Hazard Characterization – Considerations, William H. Farland, Ph.D., ATS, April 5, 2012

lifetime of exposure for the population, including sensitive subpopulations and life-stages, with exposure values that represent the greatest part of a lifetime exposure. In other words, it is appropriately health protective to assess chronic exposure scenarios for a chemical like sulfolane by using an RfD-like value with an adult body weight and ingestion rate.

An alternative approach has been chosen by the EPA Superfund program. The EPA Superfund program has developed a consensus approach to the calculation of screening levels (SLs) which are developed using EPA risk assessment guidance and can be used for Superfund sites. A discussion of SLs can be found at http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm . The SLs are described as "risk-based concentrations derived from standardized equations combining exposure information assumptions with EPA toxicity data. SLs are considered by the Agency to be protective for humans (including sensitive groups) over a lifetime." In the case of drinking water exposure, SLs include an assumption that the use of a chronic RfD-like value, coupled with an assumption of exposure parameters of 1 liter per day consumption for a 15 kg child, will generate a drinking water SL that is protective for the population with a lifetime of exposure. While the SL takes a more conservative approach, the HA value and the SL differ only by a factor of 2.3 times (70kg/2liters/day divided by 15kg/1liter/day). USEPA is clear to point out that SLs are generic screening values, not *de facto* cleanup standards.

It should also be noted that this 2.3x difference is well within the inherent uncertainty of the RfD-like estimate itself. This difference between the HA and SL approaches can be contrasted with the magnitude of the composite uncertainty factor which renders the estimate of the RfD-like value to be hundreds to thousands of times below observed subtle non-carcinogenic effects in animals, even at human equivalent concentrations (HECs). In the case of the sulfolane data, blood cell effects with unknown toxicologic significance. Additional insights which might inform the choice of drinking water exposure parameters include minimal concern for sulfolane carcinogenicity, based on lack of a proposed mode of action and negative data from the study of a chemical analog. Effects in a reproductive studies are only seen at exposure levels which are higher by an order of magnitude or more. Frank effects after acute exposures have only been observed at even higher levels.

As mentioned previously, exposures at the level of drinking water Lifetime HAs are not expected to cause any adverse non-carcinogenic effects for a lifetime of exposure. Unlike the case for sulfolane, the SL approach is designed to generate acceptable levels of contaminants for both carcinogenic and non-carcinogenic effects and to account for the possibility of shorter-term, age-specific exposures leading to toxicity, in the absence of test data to address these issues. While some groups, such as ATSDR, have coupled chronic RfD-like values with even lower body weights (10 kg) and low consumption levels (1 liter/day) to set action levels that are purported to be "protective" for infants, given the results of the sulfolane studies and the approach used to derive the RfD-like values, there is no reason to believe that this more conservative approach is warranted to protect public health. Infants and children remain at these average body weights for a short period of time and sulfolane does not accumulate in the body. In addition, unless irreversible or acute responses are predicted, or infants are expected to be unusually susceptible to an observed effect, there is no reason to believe that the less conservative approaches described by the USEPAs Drinking Water Program will not be protective of the entire population, including infants, for a full lifetime of exposure. Neither concern for carcinogenicity nor for short-term, age-specific exposures is applicable given what is known about sulfolane.

Sulfolane Hazard Characterization – Considerations

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Introduction

This set of considerations on the hazard characterization of sulfolane is being prepared at the request of Flint Hills Resources. It is based on an independent assessment of the toxicological data available for sulfolane as well as the various efforts that have been made by others to put these data and observations into a risk assessment context. These considerations rely heavily on the previous efforts but provide a more holistic view in order to assure that decision-makers in Alaska have the information needed to make reasonable, public health-protective judgments regarding potential exposure to sulfolane.

These perspectives represent my collective expertise and experience over more than thirty years as a scientist, toxicologist and risk assessment practitioner. I am currently the Vice President for Research at Colorado State University in Fort Collins, CO. I am also a Professor in the Department of Environmental and Radiological Health Sciences, School of Veterinary Medicine and Biomedical Sciences at that institution. I hold a Ph.D. (1976) from UCLA in Cell Biology and Biochemistry. In 2006, I completed 27 years of Federal service in research and development with the U.S. Environmental Protection Agency, leaving as the Deputy Assistant Administrator for Science. I have served on a number of executive-level committees and advisory boards within the Federal government and in the private sector. I served as Chair of an External Advisory Group for the National Institute of Environmental Health Sciences (NIEHS) on the future of the Superfund Basic Research Program. I currently serve as Chair of a standing committee on emerging science for environmental health decisions of the National Research Council (NRC) of the National Academy of Sciences and a member of an NRC Committee to Develop a Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials. In 2002, I was recognized by the Society for Risk Analysis with the "Outstanding Risk Practitioner Award," and in 2005 was appointed as a Fellow of the Society. In 2006, I received a Presidential Rank Award for my service as a federal senior executive. In 2007, I was elected as a Fellow, Academy of Toxicological Sciences. I continue to teach and publish and have been a member of the Editorial Board and reviewer for Risk Analysis, Environmental Health Perspectives and Chemosphere.

Executive Summary

The database on sulfolane has been evolving over the last three decades. Relatively speaking, compared to other industrial chemicals encountered in the environment, the available data and details of their generation are quite robust. A picture emerges of sulfolane, as a minimally toxic chemical at low levels in a variety of animal test systems. The effects seen a low doses represent subtle changes which are generally considered to be of unclear toxicological significance and may represent reversible, "adaptive" responses rather than precursors to toxicity. The recent

assessments have illustrated the differences in opinion and policy judgments that can arise when subtle effects with questionable toxicological significance lead to identification of points of departure (POD's) for risk assessment purposes. This lack of consensus on which study to use as the "critical study" and the lack of a consistent method of assessment supports the argument that the observations in these studies provide an uncertain basis for health risk assessment and provide "screening-level values" at best. The assessment activities discussed above have produced a provisional health guidance value (ATSDR) and provisional peer-reviewed toxicity values including a provisional RfD (EPA). It is important to remember that these RfD-equivalent values are not boundaries between safety and risk. A variety of uncertainties are present when extrapolating from such effects in animals to human populations and from partial lifetime studies in animals to longer term potential exposures in humans. Many of these uncertainties are inherent in the policy choices available to risk assessors and are compounded when multiple policy choices are chosen in a given assessment like that for Sulfolane. Calculation of a "safe" drinking water level based on such policy choices would result in a level that is thousands of times below the level where the subtlest potential adverse effects were NOT seen in the animal studies and about 11,000 times below the level where these subtle effects of unknown toxicologic significance were seen. This suggests that at these drinking water levels of sulfolane there would likely be no appreciable risk to exposed human populations.

Toxicity Data Base for Sulfolane

Relatively speaking, compared to many chemicals encountered in the environment, sulfolane has been well studied. The details of these studies and their use in a risk assessment context has been presented previously by the British Columbia Ministry of Water, Land and Air Protection (BCMWLA, 2001); Canadian Council of Ministers of the Environment (CCME, 2006); Alaska Department of Environmental Conservation (ADEC, 2006); ToxStrategies (2009, 2010, 2011); Texas Commission on Environmental Quality (TCEQ, 2011); Agency for Toxic Substances and Disease Registry (ATSDR, 2010, 2011); and US Environmental Protection Agency (USEPA, 2012a). These assessments have considered a historical data base developed over two decades from the mid-1970's to the early 2000's.

Although sulfolane has not been the subject of many studies in the peer-reviewed, published scientific literature, several well conducted studies have been reported and subsequently peer reviewed. The majority of these reports contain sufficient information to judge the details and the quality of the work presented. In the case of the studies by Zhu et al (1987), follow-up evaluations have pointed out the lack of detail in the reporting of these studies and their shortcomings for use in up-to-date risk assessment. Although no lifetime studies are available, the data base is robust with acute, subchronic and developmental/reproductive screening data. One study was a study of six-month duration, which is twice as long as a typical subchronic study. In these studies, multiple species were examined and in several studies, comprehensive pathology evaluation was performed. Acute toxicity data are available from several studies in multiple species by multiple routes. Results suggest an LD 50 value around 2 g/kg/day. To put this dose in perspective, it is equivalent to the "limit test" dose of 2 g/kg/day for acute toxicity that is used nationally and internationally to test chemicals to determine that they have a minimal degree of toxicity.

Aside from frank effects seen in acute studies within an order of magnitude (factor of ten) of the very high doses causing lethality, other manifestations of toxicity are lacking in longer term, lower dose studies. The partial lifetime (subchronic) studies in particular suggest toxicological investigations without appreciable low dose toxicological effects. Carcinogenicity does not appear to be of concern since genotoxicity studies have been mostly negative and a lifetime cancer study in animals of a similar compound (sulfolene) raised no concerns. The focus of attention at low doses in subchronic studies has been on the observation of subtle changes which are generally considered to be of unclear toxicological significance.

An example of the effects that are currently the focus of the assessment process includes the subtle effects seen in the well conducted Huntington Life Sciences study (HLS, 2001). In this study, investigators reported statistically significant decreases in white blood cell (WBC), lymphocyte, monocyte, and large unstained cell counts in female rats given 100 mg/l (10.6 mg/kg/day) or more sulfolane. To put these observations in context, the HLS study investigators concluded that the toxicological significance of the effects on WBC counts was unclear due to the lack of evidence of any chronic inflammatory change or compromised immune function in female rats, even though these decreases were statistically significant relative to the concurrent control animals. In addition, these investigators failed to detect any effects on bone marrow, thymus or spleen that might provide a biological basis for reduced numbers of white blood cells. Despite the fact that the three highest doses produced a statistically significant reduction on WBC counts compared to concurrent controls, the questionable significance of these effects as an indication of toxicity is supported further when the effects are compared to historical control female counts. Using this larger population of control animal values, ToxStrategies (as reported in ToxStrategies' Sulfolane White Paper Update, 2010), demonstrated that the "reduced values" seen in the HLS study were within the range of historical controls. Similarly, the Zhu et al. (1987) study found subtle changes in the liver (fatty deposits) and WBC counts in another test species, the guinea pig. These endpoints, which have been the focus of some risk assessment and health screening values, are considered "non-specific." They are not associated with a particular toxicity or disease and are, in fact, quite common manifestations of adaptive rather than adverse responses. They do not easily project into specific health concerns for exposure to sulfolane.

Differentiation between an adverse effect and an adaptive response is central to toxicology and is a critical determination in the context of toxicity testing approaches. In a recent publication, Keller et al (2012) discuss the importance of this distinction to toxicity testing and risk assessment. The identification of an adverse outcome after xenobiotic exposure has been a mainstay for assessing risk to inform risk management decisions. Adverse effects used for these decisions tend to be apical outcomes such as tumors, permanent changes in the target tissue, or specific transient changes in the target tissue directly associated with the ultimate outcome of concern. This manuscript defines adverse and adaptive responses as follows:

Adverse Effect: A change in morphology, physiology, growth, development, reproduction, or life span of a cell or organism, system, or (sub)population that results in an impairment of functional capacity, an impairment of the capacity to compensate for additional stress, or an increase in susceptibility to other influences.

Adaptive Response: In the context of toxicology, the process whereby a cell or organism responds to a xenobiotic so that the cell or organism will survive in the new environment that contains the xenobiotic without impairment of function.

In the absence of the linkage of observations like those described above with potential human disease outcomes, the distinction between adverse and adaptive becomes blurred and use of these endpoints for other than screening purposes becomes problematic.

Lack of Scientific Consensus on the Selection and Use of a Particular "Critical Study"

The most recent assessments from governmental bodies (ATSDR, 2010, 2011; EPA, 2012a) have illustrated the differences in opinion that can arise when subtle effects with questionable toxicological significance lead to identification of points of departure (POD's) for risk assessment purposes. ATSDR's decision as to what study to rely on as the critical study hinged on whether the study had been published in the open literature (the Zhu et al. studies). ATSDR chose to use the Zhu studies to set an "action level" despite the fact that the publications are in an obscure, local Chinese journal, lacked experimental and statistical detail and presented decisions on the level of no observed adverse effect levels (NOAELS) that are unsupported by a statistical analysis of the data. Additional arguments made by ATSDR for use of these studies include an assessment that they report data from a more "sensitive" species, guinea pigs, when compared to observations in rats in the HLS study. EPA in its final PPRTV document does not rely on the Zhu et al. studies despite the fact that several EPA toxicologists participated in the ATSDR document review. EPA states that "This report appears to be an extended abstract of the original study with very little useful information for risk assessment purposes. There is, for example, no clear indication of histopathological examination of any tissues in any test described, save for the spleen and liver in the 6-month study. This lack of results precludes assigning any effect levels at least to the 90-day test reports." In a recent Research Concept document (NTP, 2011), citing similar concerns, NTP opined that evidence that the guinea pig may be more sensitive than rats is "suggestive" at best. In its most recent assessment, ATSDR chose to use a benchmark dose (BMD) approach to determine a POD. Use of a BMD approach is consistent with more modern approaches to risk assessment and moves away from the NOAEL approach that was used in its previous assessment (ATSDR, 2010).

EPA (2012), on the other hand, chose to rely on the HLS (2001) study as its critical study. EPA explains this decision by saying "The methods in the Huntingdon Life Sciences study are well documented, and the study adheres to GLP guidelines. Additionally, the study authors conducted the drinking water study at a lower dose range and examined a wider array of endpoints than the other available studies, and thus, the study was able to detect more sensitive effects of sulfolane." The EPA concluded that confidence in the HLS study was "high." However, despite a variety of available approaches to BMD analysis with precedence in other EPA assessments, including log transformation of the experimental doses, EPA chose to rely on a NOAEL approach to evaluating the HLS data (2001). EPA also chose to use the maximum recommended uncertainty factor for its chronic PPRTV value. EPA's confidence in this value is considered "medium" despite its "high" confidence in the HLS study data.

This lack of consensus on which study to use as the "critical study" and the lack of a consistent method of assessment supports the argument that the observations in these studies provide an uncertain basis for health risk assessment and provide "screening-level values" at best.

Uncertainty in the RfD-Equivalent Value

EPA, in its Integrated Risk Information System glossary, defines a reference dose (RfD) as an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It can be derived from a NOAEL, LOAEL, or benchmark dose, with uncertainty factors generally applied to reflect limitations of the data used. The RfD is the approach generally used in EPA's noncancer health assessments. Durations include acute, short-term, subchronic, and chronic and are defined individually in the glossary. Other Agencies, including ATSDR and State Agencies, have adopted similar approaches. As defined, an RfD-equivalent value contains inherent uncertainty of perhaps an order of magnitude and is not a precise value. This uncertainty is considered to extend to approximately a factor of three on either side of the stated value. While operationally, a POD represents a single number, it should be remembered that the POD also contains inherent uncertainty dependent on the dose spacing in the critical study supporting the assessment or on the BMD model used to set the POD.

The assessment activities discussed above have produced a provisional health guidance value (ATSDR) and provisional peer-reviewed toxicity values including provisional chronic and subchronic RfDs (EPA). ATSDR's guidance value has led to their development of an action level for drinking water exposures to sulfolane. In describing its action level, ATSDR says "Simply put, an action level is intended to serve only as a screening tool to help decide whether to evaluate more closely exposures to a substance found at a site (ATSDR 2005). Exceeding the recommended action level supports the need for additional assessment of site conditions." Exceeding the action level should not be construed as representing a true health risk given the uncertainty in the number and the conservative approaches used in its derivation. ATSDR chose to use the 1.5 mg/kg/day Benchmark Dose Low (BMDL) on the dispersion of the spleen's white pulp from the Zhu et al. study. In 2011, ATSDR recommended a total uncertainty factor of 1000 (10 for animal to human extrapolation, 10 for variability in human sensitivity, and 10 for extrapolation of an intermediate dose to a chronic dose), resulting in a sulfolane guidance level of 0.002 mg/kg/day. Despite the fact that the 2011 evaluation was based on the same Zhu et al. results as were used in 2010, the 2011 evaluation incorporated an additional uncertainty factor for intermediate to chronic exposure, as compared with ATSDR's 2010 Health Consultation. The reason given for adding an additional factor of 10 was to account for "the longer duration of exposure apparently occurring at this site." It is unclear why this perspective should be new compared to the 2010 assessment. So, despite the use of a modeling approach which increased the estimate of a POD level likely to be without appreciable risk from 0.25 mg/kg/day to 1.5 mg/kg/day, ATSDR did not significantly change its action level estimates. In essence, this increases the margin of exposure associated with observed subtle effects to well over 1000.

As mentioned above, EPA chose the study by Huntingdon Life Sciences (2001) as the critical study for derivation of the p-RfD (provisional RfD). The critical endpoint is decreased total and differential WBC count in female rats. BMD modeling of total WBC count in female rats was attempted consistent with EPA's BMD technical guidance (USEPA, 2000a). According to EPA (2012), the BMD analysis resulted in significant lack of fit. Because these data were not amenable to BMD modeling according to EPA, a NOAEL/LOAEL approach was employed to identify the point of departure (POD). EPA indicates that the leukocyte data provide a

consistently observed effect, and identifies a NOAEL of 2.9 mg/kg-day in females that can be established as a POD for deriving the oral subchronic and chronic RfDs. The LOAEL for this same effect in females is 10.6 mg/kg-day. EPA applies a total uncertainty factor of 300 and 3,000 for the subchronic and chronic p-RfDs respectively. Each contains uncertainty factors to account for interspecies differences (10X), intraspecies sensitivity (10X), and database sufficiency (3X). The chronic p-RfD contains an extra factor (10X) to account for use of a subchronic study to predict chronic exposure. A composite uncertainty of 3,000 is the maximum recommended composite uncertainty value according to EPA guidance. This is because it is recognized by risk assessment practitioners that individual uncertainty factors are not fully independent and overlap exists among these factors. Use of multiple factors increases the potential for over estimation of relative uncertainty. If the composite uncertainty factor exceeds 3,000, then the database generally does not support development of an RfD (USEPA, 2002), although some early assessments used a composite uncertainty factor of 10,000. A "safe" drinking water level selected using this chronic p-RfD would be 3,000 times below a NOAEL, chosen from a dose in the study that was determined to be without even a subtle effect. Therefore, the drinking water level would be thousands of times below the level where the subtlest potential adverse effects were NOT seen in the animal studies and about 11,000 times below the level where these subtle effects of unknown toxicological significance were seen.

It is important to remember that these RfD-equivalent values are not boundaries between safety and risk. The ATSDR consultation is clear on this point. Human risk is more likely as one approaches the doses producing effects in other animals. If composite uncertainty factors are low, as is the case when human data are available, the probability of effects increases quickly as the Hazard Index exceeds 1. If composite uncertainty factors are large, as in this case, choice of an exposure even an order of magnitude (factor of 10) above the RfD-equivalent screening value likely carries little to no probability of risk of adverse health implications. The use of an animal study to predict effects in humans in the absence of human data is not driven purely by science but is a science policy decision. The selection of specific UFs when developing an RfD-equivalent value also involves science policy. In any risk assessment, a number of decision points occur where risk to humans can only be inferred from the available evidence and science policy decisions are required to bridge this gap. Both scientific judgments and policy choices may be involved in selecting from among several possible inferences when conducting a risk assessment. It is important that these choices are understood and factored into decision-making regarding protection of human health. Simply compounding numerous "conservative" policy choices in the derivation process, in the absence of good scientific reason, can result in decisions which provide no more protection for human health but alarm the public, require unnecessary controls, and have social implications for the community in terms of property values, tax revenues, population growth, etc.

Coupling of Exposure Scenarios to the USEPA PPRTV or Other RfD-like Values

A variety of approaches have been taken to couple exposure scenarios to RfD-like values when setting safe drinking water levels. These range from the use of the chronic RfD-like value (in mg/kg/day) converted to the equivalent of ppb in water, assuming consumption of 2 liters of water per day by a 70 kg human to set a drinking water equivalent level (DWEL), to the application of shorter (acute or subchronic) duration RfD-like values coupled with lower body

weights and lower water consumption values to represent exposure scenarios for infants or children for a portion of their lifespan. The DWEL assumes that some fraction of the exposure will be coming through the drinking water route.

The use of an adult body weight and water consumption level has its basis in USEPA Drinking Water Standards and Health Advisories (USEPA, 2011). In this document a "Lifetime Health Advisory" is defined as "the concentration of a chemical in drinking water that is not expected to cause any adverse non-carcinogenic effects for a lifetime of exposure. The Lifetime HA is based on exposure of a 70-kg adult consuming 2 liters of water per day." One day or ten day health advisories use different assumptions regarding acute responses and a body weight of 10 kg and 1 liter a day consumption to protect infants for short durations of exposure when their body weight and consumption patterns could result in higher relative exposures. However, the assumption is that these short duration, higher exposure concerns are adequately accounted for by use of chronic RfD-like values for longer term (lifetime) exposures. Studies of "community water" consumption support these default values of 2 liters for lifetime exposure and 1 liter for infants' and children's exposure as representing the 80-90th percentile of the population values with mean consumption values being closer to half these values. It is considered fully protective of health to combine a chronic RfD-like value, which by definition is protective against appreciable risk for a lifetime of exposure for the population, including sensitive subpopulations and life-stages, with exposure values that represent the greatest part of a lifetime exposure. In other words, it is appropriately health protective to assess chronic exposure scenarios for a chemical like sulfolane by using an RfD-like value with an adult body weight and ingestion rate.

An alternative approach has been chosen by the EPA Superfund program. The EPA Superfund program has developed a consensus approach to the calculation of screening levels (SLs) which are developed using EPA risk assessment guidance and can be used for Superfund sites. A discussion of SLs can be found at http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm (USEPA, 2012b). The SLs are described as "risk-based concentrations derived from standardized equations combining exposure information assumptions with EPA toxicity data. SLs are considered by the Agency to be protective for humans (including sensitive groups) over a lifetime." In the case of drinking water exposure, SLs include an assumption that the use of a chronic RfD-like value, coupled with an assumption of exposure parameters of 1 liter per day consumption for a 15 kg child, will generate a drinking water SL that is protective for the population with a lifetime of exposure. While the SL takes a more conservative approach, the HA value and the SL differ only by a factor of 2.3 times (70kg/2liters/day divided by 15kg/1liter/day). This difference is well within the inherent uncertainty of the RfD-like estimate itself and can be contrasted with the magnitude of the composite uncertainty factor which renders the estimate of the RfD-like value to be 1-10,000 times below observed subtle effects in animals. USEPA is clear to point out that SLs are generic screening values, not *de facto* cleanup standards. The SL approach is used to assess acceptable levels of both carcinogenic and non-carcinogenic effects and accounts for the possibility of shorter-term, age-specific exposures leading to toxicity. The available toxicity data base for sulfolane supports neither a concern for irreversible effects of early exposures nor age-specific sensitivity of children. Site-specific decisions determine how the SLs will impact remediation goals.

States have developed their own guidance for deriving screening or clean-up levels. For instance, Alaska's Department of Environmental Conservation has issued an updated draft of its Risk Assessment Procedures Manual (ADEC, 2011). In this manual, the use of RfD-like values in deriving acceptable drinking water concentrations is discussed. The use of the adult weight (70 kg) and water consumption value (2 liters/day) is presented in the example. Similarly, the uncertainty in the estimates is discussed as a critical part of a site-specific human health risk assessment.

While some groups, such as ATSDR, have coupled subchronic and chronic RfD-like values with lower body weights (10 kg) and consumption levels (1 liter/day) to set action levels that are purported to be "protective" for infants, given the results of the sulfolane studies and the approach used to derive the RfD-like values, there is no reason to believe that this step is necessary to protect public health. Infants remain at these average body weights for a short period of time and, unless acute responses are predicted or infants are expected to be unusually susceptible to an observed effect, there is no reason to believe that the approaches described above will not be protective of the entire population, including infants, for a full lifetime of exposure. Neither of these reasons is applicable given what is known about sulfolane.

Use of Defaults in Risk Assessment

Throughout the history of risk assessment, practitioners have embraced the use of default values to limit the number of inference options to be considered, to replace missing or inadequate chemical-specific information, and to allow a risk assessment to continue. In 1983, the authors of the National Research Council's (NRC) report, *Risk Assessment in the Federal Government: Managing the Process* (NRC, 1983) described a default as the inference option "chosen on the basis of risk assessment policy that appears to be the best choice in the absence of data to the contrary." Much debate has surrounded the use of default values in the conduct of risk assessment. In its 1994 report, *Science and Judgment in Risk Assessment*, the NRC discusses the key defaults used by EPA and suggests that they are based on relatively strong scientific foundations, despite the fact that none can be demonstrated to be "correct" for every chemical or situation (NRC, 1994). They represent science policy choices which must be examined in light of available chemical- or site-specific information. This perspective has led to the practice of substance-specific departures from defaults and to discussions around what information, and how much, is needed to reasonably select alternative inferences in individual risk assessments. Over the last decade, EPA's risk assessment guidance has moved toward the examination of all relevant and available data first before making a conscious choice to invoke defaults or standard values (USEPA 2000b, 2004, 2005). This is a different approach from choosing defaults first and then using data to depart from them. This shift in guidance, while well founded, is not without its own controversy. In its 2009 report, *Science and Decisions, Advancing Risk Assessment*, the NRC discussed the importance of continuing to examine the evolving science underlying defaults to ensure their consistency and to define the evidentiary standards for the use of alternative inferences; and suggests the importance of the development of specific criteria for judging alternatives. (NRC, 2009). The heart of this decades' long discussion is that application of default values or standardized assumptions should always be accompanied by the evaluation of their consistency with available data and information. Risk assessments that carefully evaluate available information and rely on scientific judgment, applied to the chemical

constituent and its site-specific exposure characteristics, are typically preferred over risk assessments that make significant use of default positions.

Assessment of Margins-of-Exposure (M-O-E)

Risk assessors and decision-makers have often found it informative to compare margins-of-exposure (MOEs) for available PODs as way to put the toxicity data analysis in perspective. MOEs compare the POD divided by anticipated or desired environmental concentrations. With the multiple studies that have been published on sulfolane, a variety of subtle low dose effects have been analyzed as potential PODs. These have included effects on blood cells, male rat kidney, reproductive and developmental effects and spleen and liver effects. Depending on the effect and the approach used for analysis (observed level in a particular study e.g. NOAEL or benchmark dose assessment); different PODs might have been chosen. In the case of blood cell effects from the HLS study, PODs are in the 10's of thousands parts per billion (ppb) drinking water equivalent concentration. For kidney effects in the rats from the MHWJ studies (MHWJ, 1999), which are generally considered to be species-specific effects based on mechanisms seen only in male rats and for the reproductive and developmental effects seen in the same studies and in the Zhu study (Zhu, 1987), PODs are in the 100's of thousands ppb drinking water equivalent concentration. If spleen or liver effects were used as a POD, results from individual studies could range from just over a thousand to a million ppb drinking water equivalent concentration. As illustrated in Figure 1, at concentrations approaching the level of detection (6 ppb) or at levels representing the recent ARCADIS best estimate for a "protective" level in drinking water, MOEs are generally 2-3 orders of magnitude (hundreds to thousands) below where no subtle effect was seen or modeled in several studies. Depending on the study and dose spacing in the protocol, the actual level where these effects were seen could be an order of magnitude greater. This figure illustrates that, using the subtlest of effects seen in the various toxicity studies that have been the focus of risk assessment efforts and a variety of approaches representing best thinking among a variety of risk assessors, the MOE for sulfolane in drinking water is likely to be adequate to protect public health for populations exposed up to the current best estimate of a "protective" level coming out of the ARCADIS assessment.

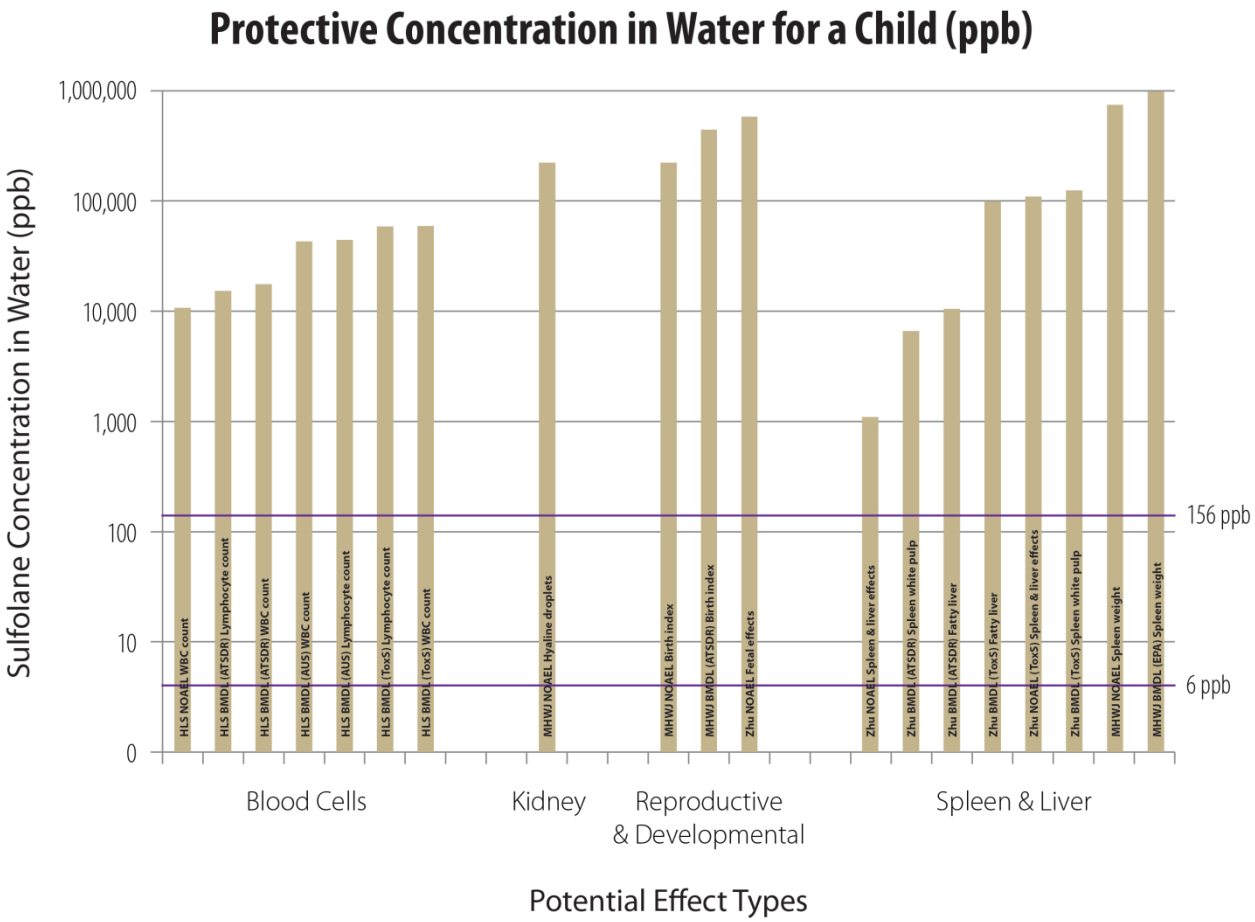

Figure1. Margins of Exposure (MOEs) based on alternative points of departure and drinking water concentrations (figure courtesy of ARCADIS)

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Perspectives on the Journal of Applied Toxicology Article entitled "Development of a chronic non-cancer oral reference dose and drinking water screening level for sulfolane using benchmark dose modeling"[1]

William H. Farland, PhD, ATS

May 30, 2014

Summary-

The database on sulfolane has been evolving over the last 3 decades. Relatively speaking, compared to many industrial chemicals encountered in the environment, the available data and details of their generation are quite robust. It has been generally recognized that there is sufficient information on sulfolane to derive scientifically-defensible toxicity values based on these data. This Journal of Applied Toxicology article provides a peer-reviewed analysis of the data and demonstrates state-of-the-science approaches to benchmark dose modeling to derive a reference dose and tap-water screening level that adhere carefully to EPA's published methods, guidance and precedents. It provides a clear explanation of the rationale for choices made, while also discussing alternatives. It provides a balanced perspective on uncertainties and opts to use public health protective values in the face of these alternatives. It compares these values with previous attempts to assess the sulfolane database and provides a significant advance over previous NOAEL/LOAEL-based efforts. Inclusion of this study, which was carried out by experienced toxicologist/risk assessors and includes one of the "fathers" of the benchmark dose (BMD) methodology, in a peer-reviewed, well respected journal suggests to me the need to re-evaluate previous efforts carried out by ATSDR and US EPA.

Methods-

The authors have provided an explanation of their approach to collection of the sulfolane toxicity testing database. Their approach is comprehensive and could easily be replicated by others, given the information provided. The only exception to this is the statement that other "proprietary resources were used when available." In reviewing the modeling efforts and results presented, there is no indication that "proprietary resources" had any impact on these efforts. The authors modeled dose-response for the noted effects using the US EPA's BMD Software (BMDS). They followed approaches suggested by EPA for both the continuous and dichotomous data sets. Model fits were evaluated, as suggested by US EPA, using criteria such as p-values, scaled residuals, Akaike information criteria, parsimony and visual inspection.

[1] Thompson, C.M., Gaylor, D.W., Tachovsky, J.A., Perry, C., Carakostas, M.C., Haws, L.C. Development of a chronic noncancer oral reference dose and drinking water screening level for sulfolane using benchmark dose modeling. J Appl Toxicol. 2012 Aug 31. doi: 10.1002/jat.2799.

Database-

The toxicologic testing database on sulfolane is relatively robust although, as mentioned by the authors, is "modest relative to some widely studied compounds." The data available include genotoxicity studies, acute and subchronic toxicity studies in multiple species by various routes of exposure, a chronic oral toxicity study, reproductive and developmental toxicity studies in multiple species by various routes of exposure and carcinogenicity studies involving sulfolene, a structurally-related compound. I have discussed the nature and quality of the database on this relatively well-studied chemical in a previous assessment (Farland, 2012). No additional, new information is included in this article.

Aside from frank effects seen in acute studies within an order of magnitude (factor of ten) of the very high doses causing lethality, other manifestations of toxicity are lacking in longer term, lower dose studies. The partial lifetime (subchronic) studies in particular suggest toxicological investigations without appreciable low dose toxicological effects. Carcinogenicity does not appear to be of concern since genotoxicity studies have been mostly negative and a lifetime cancer study in animals of a similar compound (sulfolene) raised no concerns. The focus of attention at low doses in subchronic studies has been on the observation of subtle changes, which are generally considered to be of unclear toxicological significance. Because these effects are the only ones seen at the lower doses studied, they have been modeled as if they were indications of adverse, rather than adaptive responses, to sulfolane exposure. The use of these data in this way provides a public health conservative approach to generation of a point of departure that suggests little to no toxicologic concern from the animal studies and is an uncertain indicator of potential toxicity to humans.

Given the focus of the assessment in this article on derivation of a chronic oral RfD, acute studies and those related to inhalation, irritation and sensitization were not reviewed. The summary of the studies considered in this assessment are provided in Table 1 in the article. Strengths and weaknesses of the studies are described in the text. For instance, the authors note the limited information available on the reported results of the 90-day toxicity studies by Zhu et al. (1987). They state, "Overall, these data could not be reanalyzed statistically nor were they amenable to quantitative dose-response modeling." This is consistent with a characterization of these study reports by the US EPA in their PPRTV document (US EPA, 2012a). The US EPA states, "This report appears to be an extended abstract of the original study with very little useful information for risk assessment purposes. There is, for example, no clear indication of histopathological examination of any tissues in any test described, save for the spleen and liver in the 6-month study. This lack of results precludes assigning any effect levels at least to the 90-day test reports." I concur with this assessment. The drinking water study in rats from the Huntingdon Laboratories (HLS), on the other hand, although available but unpublished, provided sufficient detail on methods and results to be useful for this assessment. The HLS study was well documented as is required of studies adhering to Good Laboratory Practice (GLP) requirements, and studied lower doses and a wider range of toxicologic endpoints than other available studies.

While likely subject to internal review at the Huntingdon Laboratories, the study was also subject to an independent peer review as part of the EPA PPRTV review process. The balance of the database was similarly assessed by the article's authors, noting similar effects in different studies where evident.

Overall, the concise description of the toxicologic database in this article appears complete and consistent with previous work. It also provides a clear and reasonable basis for the selection of the data to be modeled for dose-response, although as noted above, this represents a public health conservative approach to risk assessment given the uncertain significance of the effects observed and chosen which needs to be fully considered as the outcome of the assessment is considered and applied by decision-makers.

Dose-response modeling-

The authors of this article take the approach that, where the data allow, dose-response should be modeled rather than simply using a generally outdated NOAEL/LOAEL approach. They cite several of the nine (9) limitations of the NOAEL/LOAEL approach listed and referenced by the US EPA (2012b) in support of their approach. Use of the BMD approach is wholly consistent with the prevailing thought of the risk assessment community, in my opinion. The authors cite several references supporting this view. These include guidance from the US EPA, and the European Food Safety Agency (EFSA) as well as a recent (2010) text on quantitative methods in no-cancer risk assessment. This topic has also been part of the input by the National Research Council (NRC) on the evolution of risk assessment methods (See, for example, NRC (2009)). In addition, the NRC (2014) in its recent "Review of EPA's Integrated Risk Information System (IRIS) Process" echoes the US EPA as it references the benchmark dose approach as the "preferred" approach to setting a POD, indicating that the NOAEL/LOAEL approach should only be used if the data are inadequate for BMD modeling. The paradigm shift from the NOAEL/LOAEL approach to the preferred BMD modeling, with its use of more of the available data and focus on approximating the lower end of the range of observation, is now clearly established for appropriate data sets.

Modeling of the Zhu et al. (1987) data from the 6-month studies illustrates the authors' approach to the modeling of dichotomous data sets. The best fitting model (log-logistic) was chosen based on best fit for all three data sets. Among the three endpoints, fatty liver (steatosis) provided the lowest $BMDL_{10}$ value. Several other "alternative" dichotomous models (Davis et al., 2011) were tested and rejected based on fit and appropriateness of the model. Only one of these alternatives (dichotomous-Hill model) provided a lower BMDL value. The authors extended their analysis of this model by applying several scenarios where hypothetical higher doses and responses were modeled. Based on the results of these hypothetical scenarios and model behavior the dichotomous-Hill model was not considered appropriate for modeling these data sets. The log-logistic modeling of steatosis in the guinea pig resulted in a $BMDL_{10}$ value of 22.6 $mgkg^{-1}$ per day. I was pleased to see the rigorous attempt by the authors to assess BMD modeling for this

data set and concur with the decision that they made regarding selection of the log-logistic model. The authors reached a reasonable, data-informed conclusion that this was the most scientifically defensible POD value for the Zhu (1987) six month study.

The authors also modeled the continuous data sets from the HLS (2001) study. While this was the best documented (GLP-compliant) study in the database, the toxicologic effects on blood cells were of unclear toxicologic significance to both the study authors and multiple reviewers of the study, as previously discussed (Farland, 2012). As noted by the authors, initially none of the models in the BMDS would reasonably fit the data. One of the approaches recommended by benchmark dose modeling practitioners, including US EPA, in these circumstances is to drop the highest dose to improve the fit and place more reliance of the data closer to POD. However, recognizing that there was no evidence for frank toxicity or a plateauing of the responses, the authors reasonably rejected this approach. They did, however, recognize that the data was characterized by the two lower doses spanning a small percentage (5.5%) of the total dose range. They chose the scientifically supportable approach of log transformation of the doses to more evenly space the doses and reduce the influence of the highest dose without arbitrarily dropping it. Use of log transformation in BMD modeling is discussed by the US EPA (2012b) and is common practice among modelers (see for example, Wignall, et al. (2014)). This decision was further supported by the precedent established by US EPA in their benzene assessment (US EPA, 2002) where US EPA log transformed the doses when they modeled a reduction in lymphocytes in humans exposed to benzene to establish their RfC and RfD values. Applying the same approach, the authors of this article found a reasonable fit for linear as well as other models for total WBC and lymphocyte counts. In addition, the authors considered the use of available historical control data in lieu of the concurrent control data from the HLS study, thereby providing a "much more robust data set for establishing the normal range" which is consistent with US EPA guidance (US EPA, 2000, 2012b). The authors provide a reasonable explanation for their choice of the linear model of the log-transformed data based on well-established model selection criteria and a rationale similar to that used in the US EPA benzene assessment, i.e. parsimony (US EPA, 2002). Additionally, a dichotomous BMD analysis of the blood cell data from the HLS study as well as BMD modeling of the developmental toxicity data described by OECD (2004) was discussed by the authors.

Results of the dose response modeling efforts are presented in Table 7 of the article. PODs based on BMDL values range from 16 to 38.1 $mgkg^{-1}$ per day for the subchronic effects in rats and chronic effects in guinea pigs and at 120 $mgkg^{-1}$ per day for reproductive and developmental toxicity. The PODs represent a relatively narrow (less than one order of magnitude) range based on a variety of effects, several of which are of unclear toxicologic significance.

The approach to BMD modeling presented in this article is consistent with the state-of-the-science, rigorously applied and well explained. It is a good example of how complex data sets should be assessed for use in deriving risk reference values using today's science.

Chronic RfD derivation-

Table 7 also shows the calculated human equivalent doses (HEDs) for the PODs based on allometric scaling (BW ^{¾}) in the absence of an available comparative toxicocokinetic model, citing current US EPA practices (US EPA, 2011a). US EPA has stated that in the absence of a toxicokinetic model or other appropriate scaling approaches, "…body weight scaling to the ¾ power (i.e., $BW^{3/4}$) is endorsed as a general default procedure to extrapolate toxicologically equivalent doses of orally administered agents from all laboratory animals to humans for the purposes of deriving an oral Reference Dose (RfD). Use of $BW^{3/4}$ scaling in combination with a reduced default interspecies uncertainty factor, UFA, is recommended as the Agency default approach to replace the previous default approach for this purpose which involved $BW^{1/1}$ scaling with a full uncertainty factor (i.e., a UFA value of 10)." The authors of this article have correctly adopted this approach and have provided a robust discussion of their rationale for choice of values for the four typical uncertainty factors (UFs) employed to derive a reference value. Their clear description of their choices should engender support for this assessment, although, inevitably, as with all assessments requiring scientific judgment, there will be some discussion regarding their choices. Nonetheless, I endorse their choices based on my knowledge of risk assessment and their rationale. Ultimately, selection of the individual uncertainty factors, discussion of alternative approaches and consideration of conservatism in the name of public health resulted in composite UFs of 300 for all the PODs presented and a range of reference values of 4X (0.01-0.04 $mgkg^{-1}$ per day).

Modeled data on leukopenia from the HLS study seem to represent the most sensitive endpoint among the options presented. The authors have chosen to treat this endpoint as "adverse" despite the uncertain toxicologic significance of these effects which were noted by the study authors and reviewers. The issue of adverse versus adaptive responses in this context has been discussed elsewhere (Farland, 2012). As mentioned above, using these effects provides an extra measure of public health conservatism but, in the absence of the linkage of observations like those described above with potential human disease outcomes, the distinction between adverse and adaptive becomes blurred and use of these endpoints for other than screening purposes becomes problematic. This point should be carefully considered when applying such reference values to human health protection.

Risk-based screening level for drinking water-

The presentation of a risk-based screening level for drinking water uses the equation for an adult (70 kg) consumer of 2 liters per day over a 30 year period as is standard practice. I, along with the US EPA Drinking Water Program, have stated that it is appropriately health protective to assess chronic exposure scenarios for a chemical like sulfolane by using an RfD-like value with an adult body weight and ingestion rate. (Farland, 2012). The authors refer to the US EPA Regional screening level equations found in Superfund guidance. However, reference to the

Regional screening guidance is missing. US EPA (2011) in the article reference list is not to that guidance. I refer to it here as US EPA (2009). In addition to the adult tapwater value used in this article, this Regional guidance also shows an equation and parameters for derivation of a screening level for tapwater exposure to a child which results in a 2.3X lower regional screening level (156 versus 365 ppb). While it may be appropriate to use this approach to be fully protective of children for certain irreversibly toxic or accumulative chemicals, this does not appear to be the case with sulfolane exposure. Therefore, I can support the authors' choice of the equation and parameters in setting a risk-based screening level for drinking water. See below for further discussion.

Other points for consideration-

Within the Discussion in the article, the authors compare their findings to previous assessments, recognizing significant differences in selection of the critical study, in differences in methods for the derivation of the POD, and in selection of UFs. They also make a compelling case for the use of BMD modeling as opposed to the NOAEL/LOAEL approach when the data allow. The BMD approach for sulfolane described in this article is an improvement over previous approaches as it uses more of the data and carefully inspects the applicability of various models. In discussing the more recent US EPA provisional peer-reviewed toxicity value (PPRTV), the authors highlight the differences in methods to derive the POD, namely the lack of use of the BMD approach by US EPA. US EPA's failure to explore dose transformation and rigorously test the fit of the models as these authors have done is noteworthy. In addition, the authors point out the differences that led to US EPA using the maximal accepted composite UF (3,000) despite the reasonable scientific case that can be made for the use of lower UFs. It would appear that in the derivation of the PPRTV, US EPA (2012a) missed an opportunity to use the best available approaches and follow their own guidance. These authors have provided a compelling alternative assessment when compared to the PPRTV.

Of particular interest is the discussion of the ATSDR (2011) BMD-derived public health action level. The rationale for the use of the Zhu six-month data remains controversial as described previously. The use of the dichotomous-Hill model is problematic given the reasons articulated in the article, relating to the sensitivity of the model to the assumption of achievement of a maximal response. It is interesting to note that the authors believe that, if ATSDR had used the log logistic model, their action level would have been in the range of the reference values described above.

As mentioned previously, it is my view that it is appropriately health protective to assess chronic exposure scenarios for a chemical like sulfolane by using an RfD-like value with an adult body weight and ingestion rate. As discussed in Farland (2012), the use of an adult body weight and water consumption level has its basis in US EPA Drinking Water Standards and Health Advisories (US EPA, 2011b). In this document a "Lifetime Health Advisory" is defined as "the concentration of a chemical in drinking water that is not expected to cause any adverse non-

carcinogenic effects for a lifetime of exposure. The Lifetime HA is based on exposure of a 70-kg adult consuming 2 liters of water per day." One day or ten day health advisories use different assumptions regarding acute responses and a body weight of 10 kg and 1 liter a day consumption to protect infants for short durations of exposure when their body weight and consumption patterns could result in higher relative exposures. However, the assumption is that these short duration, higher exposure concerns are adequately accounted for by use of chronic RfD-like values for longer term (lifetime) exposures. Studies of "community water" consumption support these default values of 2 liters for lifetime exposure and 1 liter for infants' and children's exposure as representing the 80-90th percentile of the population values with mean consumption values being closer to half these values. It is considered fully protective of health to combine a chronic RfD-like value, which by definition is protective against appreciable risk for a lifetime of exposure for the population, including sensitive subpopulations and life-stages, with exposure values that represent the greatest part of a lifetime exposure.

An alternative approach has been chosen by the EPA Superfund program. The EPA Superfund program has developed a consensus approach to the calculation of screening levels (SLs) which are developed using EPA risk assessment guidance and can be used for Superfund sites. A discussion of SLs can be found at http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm (USEPA, 2009). The SLs are described as "risk-based concentrations derived from standardized equations combining exposure information assumptions with EPA toxicity data. SLs are considered by the Agency to be protective for humans (including sensitive groups) over a lifetime." In the case of drinking water exposure, SLs include an assumption that the use of a chronic RfD-like value, coupled with an assumption of exposure parameters of 1 liter per day consumption for a 15 kg child, will generate a drinking water SL that is protective for the population with a lifetime of exposure. While the SL takes a more conservative approach, the HA value and the SL differ only by a factor of 2.3 times (70kg/2liters/day divided by 15kg/1liter/day). This difference is well within the inherent uncertainty of the RfD-like estimate itself and can be contrasted with the magnitude of the composite uncertainty factor which renders the estimate of the RfD-like value to be 1,000-10,000 times below observed subtle effects in animals. USEPA is clear to point out that SLs are generic screening values, not de facto cleanup standards. The SL approach is used to assess acceptable levels of both carcinogenic and non-carcinogenic effects and accounts for the possibility of shorter-term, age-specific exposures leading to toxicity. The available toxicity database for sulfolane supports neither a concern for irreversible effects of early exposures nor age-specific sensitivity of children. Site-specific decisions, taking this issue and others discussed above into account, should determine how the SLs will impact remediation goals for sulfolane.

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Supplement to the Revised Draft Final Human Health Risk Assessment

Flint Hills North Pole Refinery
North Pole, Alaska

May 30, 2014

ARCADIS

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Supplement to the Revised Draft Final Human Health Risk Assessment

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ARCADIS

Table of Contents

ARCADIS

Supplement to the Revised Draft Final Human Health Risk Assessment

Flint Hills North Pole Refinery
North Pole, Alaska

1. Introduction

ARCADIS, U.S., Inc. (ARCADIS) prepared a *Revised Draft Final Human Health Risk Assessment for the Flint Hills North Pole Refinery* (ARCADIS, 2012). During the preparation of this risk assessment report, ARCADIS scientifically evaluated the existing Reference Doses (RfDs) and equivalent toxicological reference values for sulfolane, including those derived by the following sources: CCME (2006), ATSDR (2010, 2011), ToxStrategies (2010), TCEQ (2011) and EPA (2012a). More specifically, ARCADIS evaluated the United States Environmental Protection Agency (EPA's) Provisional Peer-Reviewed Toxicity Value (PPRTV) for sulfolane (EPA, 2012a) and concluded that EPA did not follow the best available science and EPA guidance in reaching the conclusions described in its PPRTV. In addition, ARCADIS evaluated the approach followed by ToxStrategies (2010) as described in a White Paper, entitled *Assessment of Toxicological Data for Sulfolane - Update II*. ARCADIS concluded that the RfD developed for sulfolane by ToxStrategies (2010) was based on the best available science. Nonetheless, ARCADIS independently derived a RfD for use in the risk assessment using an approach that differed modestly from that followed by ToxStrategies (2010). ToxStrategies (2010) and ARCADIS (2012) derived equivalent chronic and subchronic RfDs in accordance with the best available science and EPA guidance for evaluation of primary toxicology studies and the derivation of RfDs:

Chronic RfD	0.01 mg/kg-day
Subchronic RfD	0.1 mg/kg-day

As discussed in Section 2 below, since ARCADIS submitted ARCADIS (2012), the ToxStrategies (2010) study was independently and professionally peer-reviewed and published in the *Journal of Applied Toxicology* (Thompson, et al., 2012) ("*JAT* article"). The Thompson et al. (2012) study is a "professionally peer-reviewed document" and should be used to establish a site-specific clean-up level consistent with the toxicity hierarchy established by Alaska Department of Environmental Conservation (ADEC) in its *Risk Assessment Procedures Manual* (ADEC, 2000), which is incorporated by reference into 18 Alaska Administrative Code (AAC) 75.345. By this *Supplement to the Revised Draft Final Human Health Risk Assessment,* now that the ToxStrategies (2010) RfD derivation has been published, ARCADIS adopts and endorses the peer-reviewed analysis provided in that article and the corresponding chronic sulfolane RfD of 0.01 mg/kg-day. Based on this RfD, ARCADIS proposes and the JAT article supports a cleanup level of 362 µg/L as a health-protective standard for groundwater containing sulfolane in a residential setting.

2. The *JAT* Article Is a Newly Available, Independently Peer-Reviewed Publication Regarding the Sulfolane Reference Dose

The *Journal of Applied Toxicology* published an article based on the 2010 ToxStrategies analysis that derived a chronic RfD for sulfolane of 0.01 mg/kg-day (Thompson, et al., 2012) after the ARCADIS (2012) risk assessment was submitted. According to the publisher, the "*Journal of Applied Toxicology* publishes

peer-reviewed original reviews and hypothesis-driven research articles on mechanistic, fundamental and applied research relating to the toxicity of drugs and chemicals at the molecular, cellular, tissue, target organ and whole body level *in vivo* (by all routes of exposure) and *in vitro / ex vivo*" (Wiley, 2014). Accordingly, the work of Thompson and co-authors was carefully peer-reviewed by independent reviewers before it was published on August 31, 2012.

This peer-reviewed publication used benchmark dose modeling to derive a point of departure (POD) dose based on a benchmark response of one standard deviation difference from the mean white blood cell level in the control animals. Utilizing this approach, the authors derived a chronic RfD of 0.01 mg/kg-day. Notably, one of the co-authors of the article is Dr. David Gaylor, who has been performing original research on the benchmark dose method used in the report for decades. Dr. Gaylor is widely cited by EPA and was, in fact, a co-author of EPA's Benchmark Dose Technical Guidance (EPA, 2012b). He is a preeminent and recognized expert in the derivation of the benchmark dose and in the use of EPA's benchmark dose modeling software. As a peer-reviewed article consistent with EPA guidance, the *JAT* article supports the adoption of a chronic sulfolane RfD of 0.01 mg/kg-day under ADEC's toxicity hierarchy (ADEC, 2000).

3. The *JAT* Analysis Is Consistent with EPA Guidance and Precedent Regarding Benchmark Dose Modeling and Dose Transformation

The application of benchmark dose modeling is the principal difference between the *JAT* article and EPA's PPRTV for sulfolane (EPA, 2012a). Because the methodology of the *JAT* article is consistent with the preferred approach identified in EPA guidance (1995, 2000, 2012b, c, d; NRC, 2014; Appendix A), the *JAT* article is a more scientifically valid chronic RfD for sulfolane. The *JAT* article is consistent with EPA guidance in the following respects:

- The *JAT* article applies benchmark dose modeling, which is strongly preferred over the No Observed Adverse Effect Level (NOAEL) approach.
- The *JAT* article performed dose transformation, which is recommended by EPA when necessary to obtain adequate data fits to one or more models.
- The *JAT* article accounted for uncertainty in the RfD using uncertainty factors (UFs) selected in a manner consistent with EPA guidance and precedent.

3.1 Benchmark Dose Modeling – Guidance

The *JAT* article followed EPA guidance and used benchmark dose modeling instead of the NOAEL or Lowest Observed Adverse Effect Level (LOAEL) approach to derive the POD dose. Since the 1980's, EPA has recognized that the traditional approach for deriving RfDs by defining NOAELs or LOAELs from

toxicological studies is deficient. For instance, EPA (1995) discussed the advantages of the benchmark dose modeling approach as compared to the NOAEL approach as follows:

> Using the NOAEL in determining RfDs and RfCs [Reference Concentrations] has many limits (reviewed by Kimmel and Gaylor [1988] and others and noted by EPA's Science Advisory Board [U.S. EPA, 1986, 1988a, b, 1989]). These limitations include the following:
>
> - The experimental dose called the NOAEL is based on scientific judgment and is often a source of controversy....
> - The slope of the dose response plays little role in determining the NOAEL....
> - The NOAEL is limited to the doses tested experimentally....
>
> The EPA believes that the Benchmark Dose (BMD) approach presents a significant opportunity to improve the scientific basis of noncancer risk assessment. This document aims to encourage further application and development of the method by outlining the benchmark approach. It is hoped the BMD will add a new perspective to risk assessment and overcome some limitations of the NOAEL. To do this, the risk assessment community must first become familiar with the benchmark approach and its opportunities and limitations.

EPA continued to state its preference for the benchmark dose modeling versus the NOAEL approach over the years (EPA, 1995, 2000, 2012b, 2012c, 2012d), and in 2012, EPA issued guidance further explaining the reasons for considering benchmark dose modeling to be a more scientifically valid approach to deriving a POD dose than the use of a NOAEL (EPA, 2012b):

> The NOAEL is sometimes taken as an important point for describing a dose-response relationship in a study because of a presumed correspondence between such NOAELs and true thresholds (i.e., true no-effect levels). However, the NOAEL, which has generally been defined by a lack of statistical significance of the effect, is really a consequence of the fact that any finite study has an inherent limit of detection.
>
> ...Specific limitations of the NOAEL/LOAEL approach are well known and have been discussed extensively (Crump 1984; Gaylor 1983; Kimmel and Gaylor 1988; Leisenring and Ryan 1992; U.S. EPA 1995a):
>
> - The NOAEL/LOAEL is highly dependent on dose selection since the NOAEL/LOAEL is limited to one of the doses included in a study. . . .

- More generally, the NOAEL/LOAEL approach does not account for the variability and uncertainty in the experimental results that are due to characteristics of the study design such as dose selection, dose spacing, and sample size. . . .

- Other dose-response information from the experiment, such as the shape of the dose-response curve (e.g., how steep or shallow the slope is at the BMD, providing some indication of how near the POD might be to an inferred threshold), is not taken into account.

EPA's stated preference for the benchmark dose modeling approach extends to development of the PPRTVs. In the *Standard Operating Procedures (SOPs) for Developing Provisional Peer Reviewed Toxicity Values* (EPA, 2004), EPA states:

> If the available data are sufficient, dose-response modeling is the preferred method for determining the POD. . . . [P]roper use of this approach allows for a greater consideration of the dose-response function than the traditional NOAEL/LOAEL approach.
>
> Some advantages of using a dose-response modeling approach include:
>
> - It does not rely on the doses used in the study to determine a point of departure for calculation of risk values
>
> - It allows for the consideration of the entire dose-response curve, rather than relying on the results of a single dose level to describe the data [and]
>
> - It allows for an estimation of a NOAEL value even if the available studies report effects at every dose level examined . . . .

EPA scientists have also stated in scientific publications that the benchmark dose modeling approach is the preferred approach for the derivation of RfDs (Davis, et al., 2011; Zhao, et al., 2010). More importantly, the National Research Council recently reviewed EPA's standard practices for deriving RfDs and concluded: "Although the NOAEL-LOAEL approach remains in practice, the BMD approach is preferred because it provides and uses dose-response information to a greater extent and reduces uncertainty (EPA 2012)" (NRC, 2014). The use of benchmark dose modeling rather than the NOAEL approach in the *JAT* article is consistent with this preference.

3.2 Benchmark Dose Modeling – Precedent

EPA's preference for benchmark dose modeling is reflected in the numbers of RfDs and RfCs (both IRIS values and PPRTV values) that it has derived based on benchmark dose modeling: 68 chronic RfDs, 47

subchronic RfDs, 48 chronic RfCs, and 27 subchronic RfCs. The files for all 68 chronic RfDs were reviewed to determine the date of the RfD derivation. All 68 were dated 1997 or later, 57 (84%) were derived in 2005 or later, and 48 (71%) were derived in 2009 or later. More than half were derived in 2009 or later, showing that the benchmark dose modeling approach is being used more and more frequently.

3.3 Dose Transformation – Guidance

The *JAT* article followed EPA guidance in its approach to benchmark dose modeling. The *JAT* authors executed EPA's benchmark dose modeling software with the Huntington Life Sciences (HLS) (2001) data on white blood cells and lymphocytes and found that the data did not adequately fit any of the models. Following EPA guidance and the precedent set by EPA in the benzene reference dose derivation (discussed below), the authors log transformed the dose data and re-ran the models, obtaining adequate model fits for several of the models in the EPA software. Significantly, EPA did not take this step in preparing the sulfolane PPRTV (EPA, 2012a) and instead resorted to a NOAEL approach.

Log transformation of the data is explicitly recommended by EPA in guidance (EPA, 1995, 2000, 2012 b, c, d; Appendix A). For instance, EPA (1995) states: "...it may be necessary to transform continuous data in some cases so that they better satisfy the assumptions of a normal distribution. A log-transform is often used for this purpose." EPA (2012b) states: "Whenever none of the available models provides an adequate fit to the data, the modeler should first (re)consider data quality or experimental problems that may have been missed in the initial study evaluation (e.g., opportunistic infections, dosing errors; see Section 2.1.). Sometimes, adjustments to the data (e.g., a log-transformation of dose or adjustments for unrelated deaths) may be necessary." Similarly, when discussing acceptable adjustments to the data in the BMD Methodology Software Tutorial, EPA (2012d) states: "In certain cases, the typical models for a standard study design cannot be used with the observed data as, for example, when the data are not monotonic, or when the response rises abruptly after some lower doses that give only the background response. In these cases, adjustments to the data (e.g., a log-transformation of dose) or the model (e.g., adjustments for unrelated deaths) may be necessary." The authors of the *JAT* article followed the benchmark dose modeling approach as recommended in these EPA guidance documents.

3.4 Dose Transformation - Precedent

The approach in the *JAT* article is consistent with EPA precedents regarding the benefits of log transforming data. Importantly, dose transformation was used by EPA in its published IRIS document, *Toxicological Review of Benzene, (Noncancer Effects)* (EPA, 2002a). In the IRIS profile for benzene, EPA (2014a) states: "Most of the data were supralinear (i.e., the magnitude of the reductions in lymphocyte count decreased with increasing unit dose), and it was necessary to transform the dose data according to the formula d' = ln(d+1) in order to fit the available models." This regulatory precedent for log dose transformation concerns a data set that matches the data set for sulfolane. In both cases, the critical effect was defined as decreased white

blood cell counts; in both cases the data were supralinear; and in both cases simple log transformation of the raw data provided acceptable model fits.

Moreover, EPA routinely log transforms data when it executes the benchmark dose modeling software through the application of log-based models for dichotomous data. For instance, EPA (2012b) states with respect to dichotomous data sets: "In the absence of a biologically based model, dose-response modeling is largely a curve-fitting exercise among the variety of available empirical models." EPA further states that because there is no reason to apply one particular model "we fit a number of models to the data as show in Table A.1.2." In this table, EPA lists logistic, log-logistic, probit, and log-probit models, among others. EPA's software lists these four models in a "pull down menu" in a manner that allows the user to easily execute them both with and without log transforming the dose data. In practice, EPA routinely runs the models with log transformed doses. In addition, when running any model, whether for continuous or dichotomous data, the software contains a "pull down menu" that allows the user to transform the dose data in many different ways, including log dose transforming the data.

In addition to the many instances where EPA has run benchmark dose models after log transforming the dose data, many RfDs are specifically based on benchmark dose model runs in which the dose data were log transformed. In IRIS, there are 7 chronic RfDs based on log transformed doses out of 40 based on benchmark doses (18%) and there are 5 chronic RfCs based on log transformed doses out of 30 based on benchmark doses (17%). With regard to PPRTVs, there are 9 chronic RfDs based on benchmark doses out of 28 based on benchmark doses (32%), and there are 6 chronic RfCs based on log transformed doses out of 18 based on based on benchmark doses (33%).

Furthermore, log dose transformation has been used in a number of peer-reviewed scientific studies in which reference doses and reference concentrations were derived by benchmark dose modeling of critical effects data. Examples include:

- Budtz-Jorgensen, E., P. Grandjean, N. Keiding, R.F. White, and P. Weihe. 2000. Benchmark Dose Calculations of Methylmercury-Associated Neurobehavioural Deficits. *Toxicology Letters.* 112-113:193-9.
    - Benchmark doses that related both cord-blood and maternal hair mercury concentrations to neurobehavioral deficits in 7-year old Faroese children were calculated using a power function. The authors log (dose + 1) transformed the mercury dose parameter for benchmark dose modeling in exactly the same manner in which dose data were transformed in the *JAT* article and the EPA's benzene assessment. It was found that log transforming mercury cord-blood concentrations resulted in better model fits.
- TERA. 2005. Use of Benchmark Concentration Modeling and Categorical Regression to Evaluate the Effects of Acute Exposure To Chloropicrin Vapor Part I. Technical Report.

- Toxicology Excellence for Risk Assessment (TERA) performed benchmark concentration modeling using categorical regression to calculate a POD dose for ocular irritation associated with acute exposure to chloropicrin vapor. The final model used a log-transformed concentration (dose) parameter.

- Deutsch, R. C., & Piegorsch, W. W. 2012. Benchmark Dose Profiles for Joint-Action Quantal Data in Quantitative Risk Assessment. *Biometrics*, *68*(4), 1313-1322.

  - Benchmark dose modeling was performed using log-transformed dose data to estimate a POD dose for rates of cellular damage after human hepatic cells were exposed to various combinations of DDT and nano-TiO. The dose transformations applied in this study include $\log_{10}$(DDT dose)+4 and $\log_{10}$(TiO_2 dose)+3.

- Jiao, J., Feng, N. N., Li, Y., Sun, Y., Yao, W., Wang, W., ... & Xia, Z. L. 2012. Estimation of a safe level for occupational exposure to vinyl chloride using a benchmark dose method in central China. *J Occup Health*, *54*(4), 263-270.

  - Benchmark modeling was performed using a logistic model on log-transformed exposure concentrations to estimate safe levels of vinyl chloride exposure in workers from central China. The log-logistic model was used as the final model because it provided the best fit of three models to dose-response data.

- Wang, Q., Tan, H. S., Ma, X. M., Sun, Y., Feng, N. N., Zhou, L. F., ... & Xia, Z. L. 2013. Estimation of benchmark dose for micronucleus occurrence in Chinese vinyl chloride-exposed workers. *International journal of hygiene and environmental health*, *216*(1), 76-81.

  - Benchmark dose modeling was used to assess the dose-response relationship between occupational vinyl chloride exposure and chromosome damage in Chinese workers. Exposure concentrations were log-transformed and related to micronucleus frequency using a logistic model. The log-logistic model was selected as the final model because fitting statistics indicated that it outperformed the other five models considered.

- Wignall, J. A., Shapiro, A. J., Wright, F. A., Woodruff, T. J., Chiu, W. A., Guyton, K. Z., & Rusyn, I. 2014. Standardizing benchmark dose calculations to improve science-based decisions in human health assessments. *Environ Health Perspect*, *122*(5), 506-512.

  - Approaches were investigated for standardizing benchmark dose calculations to improve science-based decision making in human health assessments. The analysis, which included 255 chemicals with dose-response data, revealed that the log-logistic model was frequently the best performing model for describing dichotomous data sets.

4. The *JAT* Article Reports an Appropriately Protective Reference Dose That Accounts for Uncertainty in a Conservative Manner Consistent with EPA Guidance

The RfD derived in the peer-reviewed *JAT* article is conservative and appropriately health-protective for a variety of reasons. A principal reason that the RfD is health-protective is that it is based on the most sensitive endpoint reported in the HLS (2001) study, and this effect is likely not an *adverse* effect. The *JAT*

article also appropriately accounted for uncertainty by applying uncertainty factors in a manner that is consistent with EPA guidance as described below.

4.1 Endpoint Selection

The *JAT* article selected diminished white blood cell counts in female rats in the HLS (2001) study as the relevant endpoint (Thompson, et al., 2012). The *JAT* article approach is health-protective, because it is not known if the degree of white blood cell reduction observed in the study indeed resulted in an *adverse* effect or if the reduction in cells was an adaptive and reversible response. For instance, lymphocytes have a life span of 60-100 days in the rat (Suckow, 2006). Notably, EPA's IRIS dossier (EPA, 2014a) for the benzene assessment, which also used changes in blood cell counts as the relevant endpoint for setting an RfD, discussed the uncertainty associated with considering blood cell counts as adverse effects by stating: "With continuous endpoints such as hematological parameters, there is uncertainty about when a change in a parameter that has inherent variability becomes an adverse effect." Accordingly, this approach was a health protective choice that accounted for uncertainty regarding potential adverse effects of sulfolane.

As explained by Dr. Farland (2012, Appendix A), toxicologically relevant effects are those that are adverse, rather than adaptive. EPA guidance plainly provides that RfDs are based on adverse effects. EPA (1995) differentiates between adverse effects and non-adverse effects in defining a NOAEL as: "An exposure level at which there are no statistically or biologically significant increases in the frequency or severity of adverse effects between the exposed population and its appropriate control. Some effects may be produced at this level, but they are not considered as *adverse*, nor precursors to *adverse* effects." [Emphasis added] EPA recently highlighted the importance of this issue in clarifying its definition of NOAELs to require that an adverse effect be "biologically significant," not merely "statistically significant" (EPA, 2012b). A NOAEL is now defined as: "The highest exposure level at which there are no *biologically significant* increases in the frequency or severity of adverse effects between the exposed population and its appropriate control; some effects may be produced at this dose level, but they are not considered adverse or precursors of adverse effects." [Emphasis added] As described in the previous paragraph, the biological significance of the POD dose used by EPA based on the NOAEL approach is unclear.

In the absence of specific knowledge about the biological significance of a drop in circulating white blood cells from 8 billion per liter to 5 billion per liter in female rats (HLS, 2001), the *JAT* authors assumed that this was an adverse effect as a health-protective measure. Because there was no decrement in circulating white blood cells in the male animals and because that effect is not known to be an adverse effect, this approach is conservative, and the conservativeness of this approach should be considered when selecting uncertainty factors. Furthermore, the EPA default approach of setting the benchmark response at 1 standard deviation difference from the controls, which the *JAT* authors used, is also conservative given that normal ranges for circulating blood cell counts in rats are often set at +/- 2 standard deviations from the mean of control animals. Overall, assuming that this effect was adverse and using a conservative benchmark response to

define when a white blood cell decrement would be large enough to be considered *adverse* are health-protective choices that support relying on the *JAT* article for deriving a sulfolane reference dose.

4.2 Uncertainty Factors

The authors of the *JAT* article selected uncertainty factors in a manner that is consistent with EPA guidance and precedent and that resulted in derivation of an appropriately protective RfD (Appendix A). In accordance with EPA guidance (2002b), uncertainty factors were considered for the following:

- UF_A = animal-to-human (interspecies)
- UF_S = subchronic-to-chronic duration
- UF_D = database uncertainty
- UF_H = inter-individual (intraspecies)

The *JAT* article and the PPRTV do not differ with respect to first three of these UFs. The authors of the *JAT* article applied a UF_A of 3 based on the use of $BW^{3/4}$ scaling, consistent with EPA guidance on body weight scaling (EPA 2011). As discussed below, this UF_A is effectively greater than the UF_A of 10 used in the PPRTV (EPA, 2012a). The authors of the JAT article also considered a value of 1 to be potentially appropriate as endorsed by TCEQ (2011), but decided to apply the more conservative UF_A of 3.

The *JAT* article used the default UF_S of 10 as did the PPRTV (EPA, 2012a).

Finally, like the PPRTV (EPA, 2012a), the *JAT* article applied a UF_D of 3. The *JAT* article could arguably have been less conservative with respect to this uncertainty factor. EPA (2002b) guidance states:

> The database UF is intended to account for the potential for deriving an under protective RfD/RfC as a result of an incomplete characterization of the chemical's toxicity. In addition to identifying toxicity information that is lacking, review of existing data may also suggest that a lower reference value might result if additional data were available. Consequently, in deciding to apply this factor to account for deficiencies in the available data set and in identifying its magnitude, the assessor should consider both the data lacking and the data available for particular organ systems as well as life stages.

Given that the *JAT* article accounted for uncertainty by choosing an endpoint effect that may be adaptive and reversible, and applying a UF_A of 3 rather than 1, there was arguably no need to further account for uncertainty through a database uncertainty factor higher than 1.

With respect to the UF_H, the *JAT* authors applied a UF_H of 3 rather than the UF_H of 10 selected by EPA in the PPRTV because decreases in white blood cells were observed only in female rats, indicating that female rats represented a sensitive subpopulation. This approach reflects EPA guidance that supports reducing the interspecies uncertainty factor from the default value of 10 in situations where "data are sufficiently representative of the exposure/dose-response data for the most susceptible subpopulation(s)" (EPA, 2002b). As a result, using the more conservative default UF_H of 10 was not necessary to achieve an appropriately health-protective RfD because the uncertainty associated with inter-individual differences in susceptibility was accounted for in the selection of the most sensitive toxicological endpoint. Both EPA in its PPRTV Standard Operating Procedures document (EPA, 2004) and Dr. Farland (2012, Appendix A) have recognized the potential for "overlap between the identified areas of uncertainty." Accordingly, in deriving a RfD, making the most conservative choices at every turn will result in a RfD that is lower than necessary to protect human health.

The composite uncertainty factor in the *JAT* article was 300, although this was effectively the same as a composite uncertainty factor of 1,200 because the authors also addressed uncertainty related to interspecies extrapolation by using body weight scaling to a Human Equivalent Dose (EPA, 2011). EPA specifies that the UF_A of 10 is comprised of a two elements, one for pharmacokinetic differences between species and one for pharmacodynamic (sensitivity) differences between species. Each of these takes a value of approximately 3. When body weight scaling is used to compute a Human Equivalent Dose, the pharmacokinetic portion of the UF_A is not needed. One only uses the remaining factor of 3 as the UF_A. The Human Equivalent Dose factor in this case is 4, not 3, so the combined UF_A is essentially equal to 12, versus the default factor of 10. The composite uncertainty factor of 300 applied after converting the rodent dose to a Human Equivalent Dose was sufficient to provide an appropriately health-protective RfD. Overall, the *JAT* author's decisions are consistent with EPA guidance, which recognizes that: "Sound scientific judgment should be used in the application of UFs to derive reference values that are applied to the value chosen for the POD derived from the available database" (EPA, 2002b).

An overview of the health-protectiveness of the *JAT* RfD can be presented by calculating the Margin of Exposure as discussed by Dr. Farland (2012). The Margin of Exposure is defined as the ratio of the dose that a human receptor receives compared to the dose that was associated with an adverse effect in the study from which the RfD was derived, in this case, an animal study. With the HLS (2001) study, the dose associated with adverse decrements in white blood cells in the entire population is unknown, because no decrements were seen in males and the decrements seen in females are not known to be adverse or irreversible. What is known is that the dose at which truly adverse effects would be expected is greater than 16 mg/kg-day, which is the POD dose based on a one standard deviation decrement from the female control animals. The ratio of >16 mg/kg-day to 0.01 mg/kg-day is >1,600. So a person receiving the RfD of 0.01 mg/kg-day every day for their entire life would be receiving a dose of sulfolane that is >1,600 times *lower* than the lowest level that caused an effect in the HLS (2001) animal study, which *may* have been an adverse effect, but also may have just been an adaptive, reversible response. A Margin of Exposure of >1,600 is

certainly adequate to protect human health, so the RfD of 0.01 mg/kg-day is conservative and health-protective.

5. Existing ADEC and EPA Guidance Supports Using an Adult Receptor as a Health-Protective Basis for an Alternative Cleanup Level

The *JAT* article presented a sulfolane "screening value" of 365 µg/L based on calculations using an adult receptor that is sufficient to protect individuals over a full lifetime of exposure. Although this level was characterized as a screening level, it was based on the same exposure assumptions regarding the appropriate receptor and other appropriate variables identified in ADEC (2008) for use in calculating a groundwater cleanup level. The *JAT* article's choice of an adult receptor is also consistent with EPA (2012e) guidance and practice in calculating health-protective drinking water standards. Overall, the result provides a health-protective level that ADEC should now adopt as a cleanup level (subject to minor adjustments for site-specific factors related to intake from fruit and vegetable consumption). As explained in ARCADIS (2012) applying site-specific assumptions about consumption of fruits and vegetables assumed to be watered with sulfolane-containing groundwater results in a slightly lower cleanup level of 362 µg/L.

5.1 ADEC Guidance

ADEC's 2008 Cleanup Level Guidance specifically provides an equation (Equation1, Table C) to use when deriving Groundwater Cleanup Levels for noncarcinogenic constituents as incorporated by reference in 18 AAC 75.340(e)(1). This equation is shown below:

$$\text{Cleanup Level (mg/L)} = \frac{\text{THQ} \times \text{RfD}_O \times \text{BW} \times \text{AT} \times 365\ \text{d/yr}}{\text{IR} \times \text{EF} \times \text{ED} \times \text{A}}$$

The parameters and their required values are listed below:

Parameter/Definition (units)	Default
THQ/target hazard quotient (unitless)	1
BW/body weight (kg)	70
AT/averaging time (yr)	30
RfD_O/oral reference dose (mg/kg-d)	Chemical-specific (Table 2)
EF/exposure frequency (d/yr)	350
ED/exposure duration (yr)	30
IR/ ingestion rate (L/d)	2
A/absorption factor	1

This equation for a 70 kg receptor who consumes 2 liters of water a day for 30 years defines an adult receptor. There is no equation for groundwater consumption by a child. The ADEC guidance specifies that the ACL for groundwater should be based on an adult receptor. These are the same exposure assumptions used in the *JAT* article and ARCADIS (2012)

5.2 EPA Guidance

ADEC's guidance is consistent with calculations used by EPA and states in accordance with the Safe Drinking Water Act (SDWA) to compute the drinking water equivalent level-the concentration of a contaminant in drinking water that will have no adverse health effect over a lifetime of potential exposure, including potential exposures to sensitive subpopulations (EPA, 2012e). The drinking water equivalent level serves as the basis for the federal drinking water standards. In addition, EPA calculates drinking water unit risk factors, which are measures of the risk associated with a chemical in drinking water, in the Integrated Risk Information System (IRIS) using adult (70 kg) exposures of 2 L/day over a lifetime. As an example, the IRIS profile for benzene (EPA, 2014a) states the following: "The drinking water unit risk was then calculated from the oral slope factor assuming a drinking water intake of 2 L/day."

Children are considered by the federal Office of Water in the calculation of One-day and Ten-day Health Advisories (HAs). The *lifetime* HA, however, is based on the adult. EPA publishes "concentrations of drinking water contaminants at which noncancer adverse health effects are not anticipated to occur over specific exposure durations - One-day, Ten-day, and Lifetime - in the *Drinking Water Standards and Health Advisories* (DWSHA) tables. The One-day and Ten-day HAs are for a 10 kg child and the Lifetime HA is for a 70 kg adult." The lifetime HA is always more protective than a One-day or Ten-day Health Advisory.

In each of the above cases, an adult receptor is used to calculate a level sufficient to provide protection against adverse effects over a lifetime of exposure (Appendix A). ARCADIS acknowledges that EPA derives Regional Screening Levels (RSLs) for all media, including groundwater, based on a child receptor. However, these are not cleanup levels or drinking water standards. They are, as their name implies, *screening levels.* These screening levels are used in the Constituent of Potential Concern selection step of a human health risk assessment to identify the constituents that will be quantitatively included in the risk assessment. In fact, the EPA webpage (EPA, 2014b) that discusses the RSLs specifically states: "The SLs presented in the Generic Tables are chemical-specific concentrations for individual contaminants in air, drinking water and soil that may warrant further investigation or site cleanup. **It should be emphasized that SLs are not cleanup standards.**" [Note: bold typeface is in the original source.]

6. Conclusions

In conclusion, the *JAT* article has reviewed the scientific data on sulfolane and has derived an appropriately health-protective RfD that is consistent with EPA guidance and precedent. The *JAT* authors' determined the POD dose using best available science by performing benchmark dose modeling and also conservatively

assumed that an observed toxicological endpoint was an *adverse* effect despite any information that such an effect was truly *adverse*. In addition, uncertainty factors were chosen using standard EPA guidance, and these factors were health-protective. Lastly, the Alternative Cleanup Level of 362 µg/Lin groundwater derived by ARCADIS using the RfD derived in the *JAT* article was derived using an adult receptor to calculate a groundwater concentration level that provided sufficient protection against adverse effects over a lifetime of exposure. The use of the adult receptor is consistent with ADEC (2008) and EPA (2012e) guidance. ARCADIS proposes and the *JAT* article supports a health-protective cleanup level of 362 µg/L for groundwater containing sulfolane in a residential setting.

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Appendix A

Perspectives on the Journal of Applied Toxicology Article entitled "Development of a chronic non-cancer oral reference dose and drinking water screening level for sulfolane using benchmark dose modeling"

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Summary-

The database on sulfolane has been evolving over the last 3 decades. Relatively speaking, compared to many industrial chemicals encountered in the environment, the available data and details of their generation are quite robust. It has been generally recognized that there is sufficient information on sulfolane to derive scientifically-defensible toxicity values based on these data. This Journal of Applied Toxicology article provides a peer-reviewed analysis of the data and demonstrates state-of-the-science approaches to benchmark dose modeling to derive a reference dose and tap-water screening level that adhere carefully to EPA's published methods, guidance and precedents. It provides a clear explanation of the rationale for choices made, while also discussing alternatives. It provides a balanced perspective on uncertainties and opts to use public health protective values in the face of these alternatives. It compares these values with previous attempts to assess the sulfolane database and provides a significant advance over previous NOAEL/LOAEL-based efforts. Inclusion of this study, which was carried out by experienced toxicologist/risk assessors and includes one of the "fathers" of the benchmark dose (BMD) methodology, in a peer-reviewed, well respected journal suggests to me the need to re-evaluate previous efforts carried out by ATSDR and US EPA.

Methods-

The authors have provided an explanation of their approach to collection of the sulfolane toxicity testing database. Their approach is comprehensive and could easily be replicated by others, given the information provided. The only exception to this is the statement that other "proprietary resources were used when available." In reviewing the modeling efforts and results presented, there is no indication that "proprietary resources" had any impact on these efforts. The authors modeled dose-response for the noted effects using the US EPA's BMD Software (BMDS). They followed approaches suggested by EPA for both the continuous and dichotomous data sets. Model fits were evaluated, as suggested by US EPA, using criteria such as p-values, scaled residuals, Akaike information criteria, parsimony and visual inspection.

[1] Thompson, C.M., Gaylor, D.W., Tachovsky, J.A., Perry, C., Carakostas, M.C., Haws, L.C. Development of a chronic noncancer oral reference dose and drinking water screening level for sulfolane using benchmark dose modeling. J Appl Toxicol. 2012 Aug 31. doi: 10.1002/jat.2799.

Database-

The toxicologic testing database on sulfolane is relatively robust although, as mentioned by the authors, is "modest relative to some widely studied compounds." The data available include genotoxicity studies, acute and subchronic toxicity studies in multiple species by various routes of exposure, a chronic oral toxicity study, reproductive and developmental toxicity studies in multiple species by various routes of exposure and carcinogenicity studies involving sulfolene, a structurally-related compound. I have discussed the nature and quality of the database on this relatively well-studied chemical in a previous assessment (Farland, 2012). No additional, new information is included in this article.

Aside from frank effects seen in acute studies within an order of magnitude (factor of ten) of the very high doses causing lethality, other manifestations of toxicity are lacking in longer term, lower dose studies. The partial lifetime (subchronic) studies in particular suggest toxicological investigations without appreciable low dose toxicological effects. Carcinogenicity does not appear to be of concern since genotoxicity studies have been mostly negative and a lifetime cancer study in animals of a similar compound (sulfolene) raised no concerns. The focus of attention at low doses in subchronic studies has been on the observation of subtle changes, which are generally considered to be of unclear toxicological significance. Because these effects are the only ones seen at the lower doses studied, they have been modeled as if they were indications of adverse, rather than adaptive responses, to sulfolane exposure. The use of these data in this way provides a public health conservative approach to generation of a point of departure that suggests little to no toxicologic concern from the animal studies and is an uncertain indicator of potential toxicity to humans.

Given the focus of the assessment in this article on derivation of a chronic oral RfD, acute studies and those related to inhalation, irritation and sensitization were not reviewed. The summary of the studies considered in this assessment are provided in Table 1 in the article. Strengths and weaknesses of the studies are described in the text. For instance, the authors note the limited information available on the reported results of the 90-day toxicity studies by Zhu et al. (1987). They state, "Overall, these data could not be reanalyzed statistically nor were they amenable to quantitative dose-response modeling." This is consistent with a characterization of these study reports by the US EPA in their PPRTV document (US EPA, 2012a). The US EPA states, "This report appears to be an extended abstract of the original study with very little useful information for risk assessment purposes. There is, for example, no clear indication of histopathological examination of any tissues in any test described, save for the spleen and liver in the 6-month study. This lack of results precludes assigning any effect levels at least to the 90-day test reports." I concur with this assessment. The drinking water study in rats from the Huntingdon Laboratories (HLS), on the other hand, although available but unpublished, provided sufficient detail on methods and results to be useful for this assessment. The HLS study was well documented as is required of studies adhering to Good Laboratory Practice (GLP) requirements, and studied lower doses and a wider range of toxicologic endpoints than other available studies.

While likely subject to internal review at the Huntingdon Laboratories, the study was also subject to an independent peer review as part of the EPA PPRTV review process. The balance of the database was similarly assessed by the article's authors, noting similar effects in different studies where evident.

Overall, the concise description of the toxicologic database in this article appears complete and consistent with previous work. It also provides a clear and reasonable basis for the selection of the data to be modeled for dose-response, although as noted above, this represents a public health conservative approach to risk assessment given the uncertain significance of the effects observed and chosen which needs to be fully considered as the outcome of the assessment is considered and applied by decision-makers.

Dose-response modeling-

The authors of this article take the approach that, where the data allow, dose-response should be modeled rather than simply using a generally outdated NOAEL/LOAEL approach. They cite several of the nine (9) limitations of the NOAEL/LOAEL approach listed and referenced by the US EPA (2012b) in support of their approach. Use of the BMD approach is wholly consistent with the prevailing thought of the risk assessment community, in my opinion. The authors cite several references supporting this view. These include guidance from the US EPA, and the European Food Safety Agency (EFSA) as well as a recent (2010) text on quantitative methods in no-cancer risk assessment. This topic has also been part of the input by the National Research Council (NRC) on the evolution of risk assessment methods (See, for example, NRC (2009)). In addition, the NRC (2014) in its recent "Review of EPA's Integrated Risk Information System (IRIS) Process" echoes the US EPA as it references the benchmark dose approach as the "preferred" approach to setting a POD, indicating that the NOAEL/LOAEL approach should only be used if the data are inadequate for BMD modeling. The paradigm shift from the NOAEL/LOAEL approach to the preferred BMD modeling, with its use of more of the available data and focus on approximating the lower end of the range of observation, is now clearly established for appropriate data sets.

Modeling of the Zhu et al. (1987) data from the 6-month studies illustrates the authors' approach to the modeling of dichotomous data sets. The best fitting model (log-logistic) was chosen based on best fit for all three data sets. Among the three endpoints, fatty liver (steatosis) provided the lowest $BMDL_{10}$ value. Several other "alternative" dichotomous models (Davis et al., 2011) were tested and rejected based on fit and appropriateness of the model. Only one of these alternatives (dichotomous-Hill model) provided a lower BMDL value. The authors extended their analysis of this model by applying several scenarios where hypothetical higher doses and responses were modeled. Based on the results of these hypothetical scenarios and model behavior the dichotomous-Hill model was not considered appropriate for modeling these data sets. The log-logistic modeling of steatosis in the guinea pig resulted in a $BMDL_{10}$ value of 22.6 $mgkg^{-1}$ per day. I was pleased to see the rigorous attempt by the authors to assess BMD modeling for this

data set and concur with the decision that they made regarding selection of the log-logistic model. The authors reached a reasonable, data-informed conclusion that this was the most scientifically defensible POD value for the Zhu (1987) six month study.

The authors also modeled the continuous data sets from the HLS (2001) study. While this was the best documented (GLP-compliant) study in the database, the toxicologic effects on blood cells were of unclear toxicologic significance to both the study authors and multiple reviewers of the study, as previously discussed (Farland, 2012). As noted by the authors, initially none of the models in the BMDS would reasonably fit the data. One of the approaches recommended by benchmark dose modeling practitioners, including US EPA, in these circumstances is to drop the highest dose to improve the fit and place more reliance of the data closer to POD. However, recognizing that there was no evidence for frank toxicity or a plateauing of the responses, the authors reasonably rejected this approach. They did, however, recognize that the data was characterized by the two lower doses spanning a small percentage (5.5%) of the total dose range. They chose the scientifically supportable approach of log transformation of the doses to more evenly space the doses and reduce the influence of the highest dose without arbitrarily dropping it. Use of log transformation in BMD modeling is discussed by the US EPA (2012b) and is common practice among modelers (see for example, Wignall, et al. (2014)). This decision was further supported by the precedent established by US EPA in their benzene assessment (US EPA, 2002) where US EPA log transformed the doses when they modeled a reduction in lymphocytes in humans exposed to benzene to establish their RfC and RfD values. Applying the same approach, the authors of this article found a reasonable fit for linear as well as other models for total WBC and lymphocyte counts. In addition, the authors considered the use of available historical control data in lieu of the concurrent control data from the HLS study, thereby providing a "much more robust data set for establishing the normal range" which is consistent with US EPA guidance (US EPA, 2000, 2012b). The authors provide a reasonable explanation for their choice of the linear model of the log-transformed data based on well-established model selection criteria and a rationale similar to that used in the US EPA benzene assessment, i.e. parsimony (US EPA, 2002). Additionally, a dichotomous BMD analysis of the blood cell data from the HLS study as well as BMD modeling of the developmental toxicity data described by OECD (2004) was discussed by the authors.

Results of the dose response modeling efforts are presented in Table 7 of the article. PODs based on BMDL values range from 16 to 38.1 $mgkg^{-1}$ per day for the subchronic effects in rats and chronic effects in guinea pigs and at 120 $mgkg^{-1}$ per day for reproductive and developmental toxicity. The PODs represent a relatively narrow (less than one order of magnitude) range based on a variety of effects, several of which are of unclear toxicologic significance.

The approach to BMD modeling presented in this article is consistent with the state-of-the-science, rigorously applied and well explained. It is a good example of how complex data sets should be assessed for use in deriving risk reference values using today's science.

Chronic RfD derivation-

Table 7 also shows the calculated human equivalent doses (HEDs) for the PODs based on allometric scaling ($BW^{3/4}$) in the absence of an available comparative toxicocokinetic model, citing current US EPA practices (US EPA, 2011a). US EPA has stated that in the absence of a toxicokinetic model or other appropriate scaling approaches, "...body weight scaling to the ¾ power (i.e., $BW^{3/4}$) is endorsed as a general default procedure to extrapolate toxicologically equivalent doses of orally administered agents from all laboratory animals to humans for the purposes of deriving an oral Reference Dose (RfD). Use of $BW^{3/4}$ scaling in combination with a reduced default interspecies uncertainty factor, UFA, is recommended as the Agency default approach to replace the previous default approach for this purpose which involved $BW^{1/1}$ scaling with a full uncertainty factor (i.e., a UFA value of 10)." The authors of this article have correctly adopted this approach and have provided a robust discussion of their rationale for choice of values for the four typical uncertainty factors (UFs) employed to derive a reference value. Their clear description of their choices should engender support for this assessment, although, inevitably, as with all assessments requiring scientific judgment, there will be some discussion regarding their choices. Nonetheless, I endorse their choices based on my knowledge of risk assessment and their rationale. Ultimately, selection of the individual uncertainty factors, discussion of alternative approaches and consideration of conservatism in the name of public health resulted in composite UFs of 300 for all the PODs presented and a range of reference values of 4X (0.01-0.04 $mgkg^{-1}$ per day).

Modeled data on leukopenia from the HLS study seem to represent the most sensitive endpoint among the options presented. The authors have chosen to treat this endpoint as "adverse" despite the uncertain toxicologic significance of these effects which were noted by the study authors and reviewers. The issue of adverse versus adaptive responses in this context has been discussed elsewhere (Farland, 2012). As mentioned above, using these effects provides an extra measure of public health conservatism but, in the absence of the linkage of observations like those described above with potential human disease outcomes, the distinction between adverse and adaptive becomes blurred and use of these endpoints for other than screening purposes becomes problematic. This point should be carefully considered when applying such reference values to human health protection.

Risk-based screening level for drinking water-

The presentation of a risk-based screening level for drinking water uses the equation for an adult (70 kg) consumer of 2 liters per day over a 30 year period as is standard practice. I, along with the US EPA Drinking Water Program, have stated that it is appropriately health protective to assess chronic exposure scenarios for a chemical like sulfolane by using an RfD-like value with an adult body weight and ingestion rate. (Farland, 2012). The authors refer to the US EPA Regional screening level equations found in Superfund guidance. However, reference to the

Regional screening guidance is missing. US EPA (2011) in the article reference list is not to that guidance. I refer to it here as US EPA (2009). In addition to the adult tapwater value used in this article, this Regional guidance also shows an equation and parameters for derivation of a screening level for tapwater exposure to a child which results in a 2.3X lower regional screening level (156 versus 365 ppb). While it may be appropriate to use this approach to be fully protective of children for certain irreversibly toxic or accumulative chemicals, this does not appear to be the case with sulfolane exposure. Therefore, I can support the authors' choice of the equation and parameters in setting a risk-based screening level for drinking water. See below for further discussion.

Other points for consideration-

Within the Discussion in the article, the authors compare their findings to previous assessments, recognizing significant differences in selection of the critical study, in differences in methods for the derivation of the POD, and in selection of UFs. They also make a compelling case for the use of BMD modeling as opposed to the NOAEL/LOAEL approach when the data allow. The BMD approach for sulfolane described in this article is an improvement over previous approaches as it uses more of the data and carefully inspects the applicability of various models. In discussing the more recent US EPA provisional peer-reviewed toxicity value (PPRTV), the authors highlight the differences in methods to derive the POD, namely the lack of use of the BMD approach by US EPA. US EPA's failure to explore dose transformation and rigorously test the fit of the models as these authors have done is noteworthy. In addition, the authors point out the differences that led to US EPA using the maximal accepted composite UF (3,000) despite the reasonable scientific case that can be made for the use of lower UFs. It would appear that in the derivation of the PPRTV, US EPA (2012a) missed an opportunity to use the best available approaches and follow their own guidance. These authors have provided a compelling alternative assessment when compared to the PPRTV.

Of particular interest is the discussion of the ATSDR (2011) BMD-derived public health action level. The rationale for the use of the Zhu six-month data remains controversial as described previously. The use of the dichotomous-Hill model is problematic given the reasons articulated in the article, relating to the sensitivity of the model to the assumption of achievement of a maximal response. It is interesting to note that the authors believe that, if ATSDR had used the log logistic model, their action level would have been in the range of the reference values described above.

As mentioned previously, it is my view that it is appropriately health protective to assess chronic exposure scenarios for a chemical like sulfolane by using an RfD-like value with an adult body weight and ingestion rate. As discussed in Farland (2012), the use of an adult body weight and water consumption level has its basis in US EPA Drinking Water Standards and Health Advisories (US EPA, 2011b). In this document a "Lifetime Health Advisory" is defined as "the concentration of a chemical in drinking water that is not expected to cause any adverse non-

carcinogenic effects for a lifetime of exposure. The Lifetime HA is based on exposure of a 70-kg adult consuming 2 liters of water per day." One day or ten day health advisories use different assumptions regarding acute responses and a body weight of 10 kg and 1 liter a day consumption to protect infants for short durations of exposure when their body weight and consumption patterns could result in higher relative exposures. However, the assumption is that these short duration, higher exposure concerns are adequately accounted for by use of chronic RfD-like values for longer term (lifetime) exposures. Studies of "community water" consumption support these default values of 2 liters for lifetime exposure and 1 liter for infants' and children's exposure as representing the 80-90th percentile of the population values with mean consumption values being closer to half these values. It is considered fully protective of health to combine a chronic RfD-like value, which by definition is protective against appreciable risk for a lifetime of exposure for the population, including sensitive subpopulations and life-stages, with exposure values that represent the greatest part of a lifetime exposure.

An alternative approach has been chosen by the EPA Superfund program. The EPA Superfund program has developed a consensus approach to the calculation of screening levels (SLs) which are developed using EPA risk assessment guidance and can be used for Superfund sites. A discussion of SLs can be found at http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm (USEPA, 2009). The SLs are described as "risk-based concentrations derived from standardized equations combining exposure information assumptions with EPA toxicity data. SLs are considered by the Agency to be protective for humans (including sensitive groups) over a lifetime." In the case of drinking water exposure, SLs include an assumption that the use of a chronic RfD-like value, coupled with an assumption of exposure parameters of 1 liter per day consumption for a 15 kg child, will generate a drinking water SL that is protective for the population with a lifetime of exposure. While the SL takes a more conservative approach, the HA value and the SL differ only by a factor of 2.3 times (70kg/2liters/day divided by 15kg/1liter/day). This difference is well within the inherent uncertainty of the RfD-like estimate itself and can be contrasted with the magnitude of the composite uncertainty factor which renders the estimate of the RfD-like value to be 1,000-10,000 times below observed subtle effects in animals. USEPA is clear to point out that SLs are generic screening values, not de facto cleanup standards. The SL approach is used to assess acceptable levels of both carcinogenic and non-carcinogenic effects and accounts for the possibility of shorter-term, age-specific exposures leading to toxicity. The available toxicity database for sulfolane supports neither a concern for irreversible effects of early exposures nor age-specific sensitivity of children. Site-specific decisions, taking this issue and others discussed above into account, should determine how the SLs will impact remediation goals for sulfolane.

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