
Migration to Indoor Air Calculations for Use in the Hydrocarbon Risk Calculator

Technical Background Document and Recommendations

Prepared for
Alaska Statement of Cooperation Working Group

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Preface

This document was created under the Alaska Statement of Cooperation (SOC), which is an agreement between the Alaska Department of Environmental Conservation (ADEC), the U.S. Environmental Protection Agency (EPA), the Departments of the Army, Air Force, Navy, Military and Veterans Affairs (Army National Guard), Interior, and the Federal Aviation Administration (FAA) and U.S. Coast Guard. The objective of the agreement is to work cooperatively to identify and resolve issues affecting human health and the environment through promoting compliance with environmental laws, preventing pollution, creating partnerships to identify and cleanup contaminants and pollution, promoting training and coordinating with affected Tribes. A subcommittee or “working group” was formed under the SOC to evaluate the characterization and fate and transport of petroleum hydrocarbons spilled in the environment, and the risks posed by petroleum contamination. FAA contracted with Geosphere and CH2M Hill to research the issues and develop eight technical issue papers. The paper titles are listed below. Staff from ADEC, FAA, the Army and Army Corps of Engineers, and the Army National Guard reviewed and provided feedback on the draft papers. These papers provide sound scientific and technical information along with recommendations for use and/or future consideration.

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Statement of Cooperation Working Group Paper Titles

1. Three- and Four-Phase Partitioning of Petroleum Hydrocarbons and Human Health Risk Calculations, Technical Background Report Document and Recommendations
2. Hydrocarbon Characterization for Use in the Hydrocarbon Risk Calculator and Example Characterizations of Selected Alaskan Fuels, Technical Background Document and Recommendations
3. Dilution-Attenuation Factors at Fuel Hydrocarbon Spill Sites, Technical Background Document and Recommendations
4. Maximum Allowable Concentration, Residual Saturation, and Free-Product Mobility, Technical Background Document and Recommendations
5. Groundwater Sampling Techniques for Site Characterization and Hydrocarbon Risk Calculations, Technical Background Document and Recommendations
6. Migration to Indoor Air Calculations for Use in the Hydrocarbon Risk Calculator, Technical Background Document and Recommendations
7. Site Conditions Summary Report for Hydrocarbon Risk Calculations and Site Status Determination, Technical Background Document and Recommendations
8. Proposed Environmental Site Closeout Concepts, Criteria, and Definitions, Technical Background Document and Recommendations

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Acronyms and Abbreviations

AAC	Alaska Administrative Code
ADEC	Alaska Department of Environmental Conservation
BTEX	benzene, toluene, ethylbenzene, and total xylenes
DRO	diesel-range organics
EPA	U.S. Environmental Protection Agency
GRO	Gasoline-range organics
NAPL	nonaqueous-phase liquid
PAH	polycyclic aromatic hydrocarbon
RRO	residual-range organics
SOCWG	Alaska Statement of Cooperation Working Group
TPH	total petroleum hydrocarbon
UCL	upper confidence limit

SECTION 1

Introduction

It is the responsibility of the U.S. Environmental Protection Agency (EPA), Alaska Department of Environmental Conservation (ADEC), responsible parties and environmental consultants to reduce and/or control the risks to human health posed by fugitive hydrocarbons in the environment. ADEC currently regulates exposure to fuel hydrocarbons via the soil ingestion, groundwater ingestion, and migration to outdoor air exposure routes by publishing soil and groundwater screening levels (18 Alaska Administrative Code [AAC] 75). The contaminated site regulations note that the listed screening values may have to be modified to account for other exposure pathways such as the migration to indoor air pathway (18 AAC 75.340(i)(2)(A)(i)). However, in recent years research has indicated that fuel hydrocarbon vapors in soil gases have the potential to migrate to indoor air at concentrations that may present an inhalation hazard above acceptable risk levels.

This technical background document describes the migration to indoor air exposure route and documents the approach used in the hydrocarbon risk calculator to assess human health risk associated with the migration to indoor air route. The Alaska Statement of Cooperation Working Group (SOCWG) recognizes that the science related to the assessment of risks posed by the migration to indoor air route is evolving and that the approach to addressing this route presented here is likely to change with time. The SOCWG also recognizes that the migration to indoor air route may commonly be the highest-risk and/or most commonly completed exposure pathway; therefore, the inclusion of the migration to indoor air risks in cumulative risk calculations, and in current and future land use and land management decisions, is critical.

1.1 Purpose and Objectives

The purpose and objectives of this technical background document are as follows:

- Briefly describe the migration to indoor air exposure route
- Integrate a characterization of the risk posed by the migration to indoor air into the hydrocarbon risk calculator
- Provide an assessment of the sensitivity of the calculation risk output values to the soil and building input parameters (the sensitivity analysis provided is borrowed, with reference, from an EPA document)
- Characterize the risk posed by the migration to indoor air route for several commonly used Alaskan fuels

This technical background document builds on the information presented in the technical background documents on phase partitioning, hydrocarbon characterization, site characterization and site closeout (Geosphere and CH2M HILL, 2006a, b, c, and d).

SECTION 2

Migration to Indoor Air Route Background Information

The migration to indoor air (or vapor intrusion) route is the movement of volatile chemicals from the soil gas into the air space of overlying buildings. The source of the volatile chemicals can be buried wastes, spilled liquids in the soil, or contaminated groundwater from an upgradient site. In Alaska, fugitive petroleum hydrocarbons from fuel handling and storage facilities are the most common type of contaminant listed in the ADEC contaminated sites data base, and many of the constituents in the fuels are sufficiently volatile and toxic or carcinogenic to potentially cause unacceptable indoor air risks. Hence, this document focuses on fuel hydrocarbons, although the concepts apply to organic compounds in general. Figure 1 shows a conceptual site model for the migration to indoor air route.

As described in the technical background on phase partitioning (Geosphere and CH2M HILL, 2006a), hydrocarbon constituents tend to partition between the vapor, adsorbed, dissolved, and nonaqueous-phase liquid (NAPL) phases to establish a local equilibrium. The concentration of a fuel hydrocarbon compound in the vapor phase is a function of its total concentration in the soil environment, the concentration of the other fuel constituents, its phase partitioning relationships (quantified by Raoult's Law, Henry's Law, soil-water partitioning coefficients, etc.) and the soil characteristics (porosity, moisture content, organic carbon content, etc.). The vapor-phase molecules tend to migrate from areas of high vapor concentration to areas of low vapor concentration by diffusion (as described by Fick's Laws). Near buildings, the soil gases, including the hydrocarbon vapors, tend to be drawn into under-pressurized buildings, through cracks in the building foundation (buildings with slab-on-grade foundations, unfinished crawl spaces, and poured concrete basements are susceptible). Buildings may be under-pressurized relative to the soil environment as a result of ventilation/heating of the building and/or winds blowing over the building. In Alaska, the presence of an ice-rich seasonal frost layer near the ground surface may exacerbate the advection of soil gases into buildings. High concentrations of fuel hydrocarbons accumulating in buildings could potentially lead to explosion hazards, acute exposures, or aesthetic problems (odors). Low concentrations of fuel hydrocarbon vapors could go undetected while causing a chronic exposure health risk. Assessment of the risk posed by the migration to indoor air route is complicated by the presence of many volatile compounds in the indoor air space from sources in the building itself (such as gasoline in attached garages, household cleaners, paints and thinners, etc.).

2.1 EPA 3-Tiered Assessment

EPA has developed a 3-Tiered approach for addressing risks associated with the migration to indoor air pathway that is documented in draft guidance (EPA, 2002; final EPA guidance on the vapor intrusion route is expected in 2006). The EPA approach focuses on protection of the public in a residential setting but may be also applied to other land uses (recreational/ industrial). Each of the three Tiers of assessment for the vapor intrusion route are designed to

separate sites that may present unacceptable risks from sites that do not present unacceptable risks. Each successive Tier involves increasing levels of conceptual complexity and specificity and has greater field data requirements. The 3-Tiered approach applies EPA “data quality objectives” concepts and requires use of a “site conceptual model” to help evaluate data and make informed decisions as to whether the vapor intrusion route is complete and the risk is therefore present. The three Tiers are described below.

Tier 1. Tier 1 is a primary screening that asks the following questions:

1. *Are compounds that have the potential to create a migration to indoor air risk present at the site?* To help answer this question the EPA provides a list of compounds that are thought to be sufficiently volatile and toxic to present potential risks. Compounds with Henry’s Constants above 10^{-5} atm m³ /mol are considered sufficiently volatile for inclusion on the list; and compounds with a pure phase vapor concentration that produces an inhalation hazard index greater than 1 or an incremental lifetime cancer risk greater than 10^{-6} are considered sufficiently toxic for inclusion on the list. The common fuel hydrocarbon compounds regulated by the ADEC that are on the EPA list are shown on Table 1 (EPA, 2002; Table 1). The complete list is available on the EPA Web site. If the site in question does not contain any of the compounds on the EPA screening list, then further evaluation of the vapor intrusion route is not necessary. If compounds on the list are thought to be present at the site, then a Tier 2 evaluation will likely be necessary.
2. *Are inhabited buildings present or will they likely be present at the site under future development scenarios?* The migration to indoor air route can be considered incomplete if there are no buildings at the site and if no buildings will be constructed at the site in the future. However, if there are buildings at the site or if buildings might be constructed at the site in the future, then the assessment of the vapor intrusion route should progress to Tier 2. The EPA considers buildings within about 100 feet of a source to be present at the site. Assurance that no buildings will be constructed at the site in the future will likely require a formal institutional control such as a publicly recorded deed restriction.
3. *Do current conditions at the site warrant immediate action?* Conditions that might warrant immediate action include strong indicators that the vapor intrusion route is complete (for example, conditions such as chemical or fuel odors in buildings; physiological effects on building inhabitants, such as nausea or dizziness; or wet basements or crawl spaces in an area of known fuel spills). If these types of indicators are present, then immediate action is warranted and a Tier 2 assessment is not sufficient. If these conditions are not present and the site has chemicals on the EPA list and has the potential for occupied buildings, then a Tier 2 assessment is necessary.

Tier 2. Tier 2 is a secondary screening of the vapor intrusion route that removes some of the conservatism of Tier 1 but requires more site specific data to implement. A Tier 2 assessment involves comparing measured or reasonably estimated concentrations in soil, groundwater, or soil gas to lookup table values. The use of the screening lookup tables benefits from an understanding of whether the contaminant source is in the vadose zone or groundwater, the depth of the contaminant, the building foundation type, and the soil moisture content. Two sets of lookup table values are available. The first set provides screening concentrations for shallow soil gas, deep soil gases, and groundwater based on attenuation rates of 0.1 for shallow soil gas, 0.01 for deep soil gas, and 0.001 for groundwater (the inhalation risk-based level is multiplied

by the attenuation factor to derive a media concentration). The building, soil, and groundwater conditions of the site are not specifically considered in these tables. The lookup tables are calculated for excess cancer risk levels of 10^{-4} , 10^{-5} , and 10^{-6} . The attenuation factors used by EPA are considered conservative, “generic” attenuation factors and are loosely based on field data. (An attenuation factor quantifies the change in concentration between the source and the indoor air concentration: $\text{attenuation factor} = \text{indoor air concentration} / \text{source concentration}$). The first set of Tier 2 EPA screening levels for the benzene, toluene, ethylbenzene, and total xylenes (BTEX) and polycyclic aromatic hydrocarbon (PAH) fuel hydrocarbons at the 10^{-5} risk level are listed in Table 2 (EPA, 2002; Table 2).

The second set of screening concentrations involves use of more site-specific data regarding soil types and depth to the vapor source to produce a table of lookup values for attenuation factors ranging from about 0.002 to 0.0002. This second set of screening values is derived from a simplified application of the Johnson & Ettinger vapor intrusion model and allows vapor concentrations that are up to 50 times greater than the concentrations in the first set of Tier 2 screening levels. The attenuation factor used to select Table 3 values is derived from the Figure 2 graphs and an understanding of the soil type and contaminant depth at the project site. The soil types listed in the Figure 2 graphs use U.S. Soil Conservation Service definitions.

If soil gas concentrations exceed the Tier 2 screening levels, then a Tier 3 assessment is recommended. If soil gas concentrations do not exceed the table screening levels, then further assessment is not necessary. Note that the EPA emphasizes the use of measured soil gas concentrations over the use of calculated soil gas concentrations during Tier 2 screening (this is especially true if there is a vadose zone source of contamination below the building at the site). The EPA also advises that the screening table values not be used if the building and soils condition assumptions are not representative of the site (for example, if there are preferential vapor migration pathways in the soil, if there is an unlined crawl space or soil floor, and/or if the building is highly under-pressurized, then the lookup tables should not be used).

The EPA recommends considering the evidence regarding vapor intrusion from the source of the vapors (such as contaminated soil or groundwater) and working toward soil gas below the foundation and then to indoor air space. Indoor air sampling is generally not recommended until the presence of vapors in the foundation soils is confirmed (this is to help differentiate vapor sources in the soil environment from vapor sources inside the building).

Tier 3. Tier 3 is a site-specific assessment of the risks posed by the vapor intrusion route. A Tier 3 assessment is generally performed only when Tier 1 and Tier 2 screening are not able to eliminate the site from further consideration. When conducting Tier 3 assessments the EPA recommends direct measurement of the (sub) foundation soil gas concentrations before measurement of the indoor air concentrations, measurement of the indoor air concentrations only in conjunction with a survey to identify indoor sources of vapors (and removal of the indoor vapor sources prior to sampling indoor air), and mathematical modeling of the soil gas data as appropriate. If buildings are not present at the site, and the evaluation of risk is performed for potential future development, then the evaluation of risk should be based on the results of mathematical model and soil gas data. If the Tier 3 assessment shows that the vapor intrusion route does pose unacceptable human health risks, then it is likely that final decisions regarding the vapor intrusion route at the site may be made.

ADEC Guidance. ADEC has issued a migration to indoor air technical memorandum (ADEC, 2005) which indicates that a site conceptual model should be used to help assess whether the migration to indoor air route is complete or could be completed in the future; and if so, then the risks associated with the migration to indoor air route should be included in the cumulative risk calculations for the site. The ADEC guidance incorporates the EPA Tier 1 screening list of compounds and the EPA Tier 2 “generic” attenuation factor lookup table screening concentrations as tools to help focus the assessment of potential risks. The guidance indicates that if soil gas concentrations are below the screening levels, then further assessment is not necessary. The ADEC guidance also indicates that gasoline-range organics (GRO), diesel-range organics (DRO), and residual-range organics (RRO) petroleum fractions do not need to be included in the risk calculations. The ADEC guidance references the EPA guidance frequently, pointing out that shallow groundwater conditions (5 feet), shallow vadose zone soil contamination under buildings, and building conditions such as unlined crawl spaces may exacerbate the vapor intrusion risks such that the EPA screening tables are not conservative. In addition, the ADEC guidance points out that the effect of seasonal frost and permafrost in Alaska on this exposure pathway has not been fully evaluated.

Johnson & Ettinger Model. The Johnson and Ettinger Model (1991) is a mathematical screening level model that describes both the diffusive transport and the pressure gradient/convective transport of soil vapors from soil or groundwater sources into overlying buildings. The model can be used to make a forward calculation of risk or a backward calculation of media cleanup levels, and can be used with an infinite or finite source assumption.

The EPA has produced several sets of Excel spreadsheets that solve the Johnson & Ettinger equation. One version of the Excel spreadsheets calculates the migration to indoor risk for volatile constituents of a multi-constituent NAPL, such as a fuel hydrocarbon. The EPA NAPL source version of the Johnson & Ettinger model can accommodate up to 10 NAPL constituents (this is less than the 16 fractions selected for use by the SOCWG), and has the option for a finite source assumption. Other EPA models using the Johnson & Ettinger equation include a set of six spreadsheets developed for the EPA by Environmental Quality Management, Inc. (2004). The six spreadsheets include simple and advanced models that relate soil hydrocarbon concentrations to indoor air hydrocarbon concentrations, soil gas hydrocarbon concentrations to indoor air hydrocarbon concentrations, and groundwater hydrocarbon concentrations to indoor air hydrocarbon concentrations. The simple spreadsheet models allow only a few model parameters to be manipulated and advanced spreadsheet models allow most or all of the input parameters to be entered. As listed in the documentation of the spreadsheets, the basic assumptions of the Johnson & Ettinger model include the following:

- Contaminant vapors enter the building through cracks in the foundation and belowgrade (basement) walls
- Convective/pressure gradient transport occurs near the building (the pressure gradient is caused by the under-pressurization of the building relative to the soil gas as a result of heating and ventilation of the building)
- Diffusive transport is dominant between the contaminant source and the building zone of convective influence (that is, further from the building)
- All vapors originating below the building will enter the building

- Soil properties are horizontally homogeneous (soil layers with differing properties may be accommodated)
- The contaminant is homogeneously distributed within the zone of contamination
- Water infiltration or evapotranspiration does not affect vapor transport
- Contaminants are not biodegraded or transformed during transport
- The soil in contact with the building foundation is isotropic with respect to permeability
- The building ventilation rate and difference in pressure between the building and soil are constant

Johnson & Ettinger Model Input Values and Sensitivity Analysis. The Johnson & Ettinger model has a relatively large number of building and soil input parameters and the accuracy of the model depends greatly on the accuracy of the data used to characterize the site-specific conditions where the model is being applied. The EPA report documenting the spreadsheet (Environmental Quality Management, Inc. 2004) provides a qualitative description of the sensitivity of the model to different input parameters, as shown in Table 4. The spreadsheet documentation provides information on the range of values and median values for different model input parameters. Some of these tables are reproduced in this report as follows:

- EPA values for the soil input parameters are shown in Table 5 and a triangular diagram showing the soil textures is reproduced as Figure 3. Note that the soil moisture content has a large impact on the attenuation factor and that higher moisture contents result in higher attenuation factors. Because of this, and because soil moisture data are easy to acquire, the collection of site-specific soil moisture data in Alaska is highly recommended. The soil moisture data should represent the long-term average moisture content of each significant strata between the vapor source and the building foundation. Due to the fluctuation in moisture contents in the near surface soils, the samples should generally be collected from the relatively deeper portion of the surficial strata (e.g., from below the 5-foot depth if the surficial strata is thicker than 5 feet).
- EPA values for some of the building (and soil) input parameters are shown in Tables 6 and 7.
- The effect of increasing the input values of selected parameters on the building concentration is shown in Table 8.

Hers et al. (2003) has evaluated how well the Johnson & Ettinger model predicts indoor air concentrations and has conducted sensitivity analyses of the effect of the input parameters on the attenuation factor. Hers found that vapor attenuation factors predicted by the Johnson & Ettinger model were similar to the measured vapor attenuation factors when appropriate soil and building input factors were used. Hers also supported the sensitivity analysis with field/pilot scale tests of the model.

SECTION 3

Approach Used in Hydrocarbon Risk Calculator

A characterization of the risk associated with the migration to indoor air route has been incorporated in the hydrocarbon risk calculator (the calculator was discussed in the technical background document on phase partitioning. [Geosphere and CH2M HILL, 2006a]). The characterization of vapor intrusion risk uses the Johnson & Ettinger model to calculate the risk posed by the soil gas concentrations in a NAPL-contaminated soil source zone. The soil gas concentrations used as input to the Johnson & Ettinger model can be: (1) measured soil gas concentrations, (2) equilibrium phase partitioning concentrations based on the 95 percent upper confidence limit (UCL) bulk soil concentrations and the “Excel Solver” iterative convergence solution to the phase partitioning equations, or (3) vapor concentrations assuming equilibrium partitioning from the measured dissolved phase concentrations (groundwater to indoor air). Recall that the EPA recommends the use of measured soil gas concentrations over the use of calculated soil gas concentrations. The SOCWG agrees that measured soil gas concentrations are desirable but understands that measured soil gas data do not exist at most Alaskan sites and that soil gas concentrations calculated by the hydrocarbon risk calculator may be used as a screening tool. If this vapor intrusion screening indicates the presence of unacceptable risk then soil gas data may be collected.

The form of the Johnson & Ettinger equation used in the hydrocarbon risk calculator is the same as that used in the EPA’s soil gas to indoor air “advanced model” (Environmental Quality Management, Inc. 2004), and it allows site- specific (or default) input values for each model variable. The soil gas concentration used in the model is the equilibrium vapor concentration calculated by the hydrocarbon risk calculator if the NAPL source is limited to the vadose zone or the vapor concentration in equilibrium with measured groundwater concentrations if the NAPL- contaminated soil source area extends into the saturated zone. In addition, if sub-foundation soil vapor concentration data are available, then these data may be used in the risk calculations. The data input that are specific to the vapor intrusion model include building parameters and soil characteristics between the NAPL source and the building foundation are shown on page two of the hydrocarbon risk calculator. An example of the data input for the vapor intrusion model is shown in Table 9.

The risks posed by each of the 16 hydrocarbon fractions and 13 PAH compounds that are addressed in the hydrocarbon risk calculator are evaluated simultaneously. The risk characterization output page (shown in Table 10) lists the hydrocarbon fractions and PAH compounds, the vapor concentrations in the soil source area, the building vapor concentration calculated by the Johnson & Ettinger model (given the input parameters), the target building vapor concentration (the risk-based concentration in the indoor air), and the “fraction of risk” associated with the compound. The fraction of risk is the building concentration divided by the risk-based building concentration (this approach is used to characterize risk for each route evaluated by the hydrocarbon risk calculator, as described in Geosphere and CH2M HILL, 2006a). Fraction of risk values less than 1 represent acceptable risk while fraction of risk values greater than 1 represent unacceptable risk. A check for compliance for each compound is

performed by assessing if the fraction of risk value is less than 1. The risks associated with the vapor intrusion route are included in the cumulative risk calculations.

If calculated soil gas concentrations are used as input to the hydrocarbon risk calculator then the results may be considered equivalent to the EPA Tier 2 or Tier 3 screening level. If measured shallow soil gas concentrations and site specific soils data are used as input to the hydrocarbon risk calculator then the results may be considered equivalent to the EPA Tier 3 risk assessment level.

SECTION 4

Vapor Intrusion Risks Associated with Fresh Alaskan Fuels

Several Alaskan gasolines, jet fuels, and diesel fuels were analyzed to assess their general composition and/or water solubility in several aromatic and aliphatic equivalent carbon groups. The results of these analyses can be used to assess the vapor concentration in equilibrium with the NAPL of each of the fuels and the potential vapor intrusion risks associated with the fuel types. The purpose of this evaluation is to better understand which compounds or hydrocarbon fractions are most likely to drive vapor intrusion risks (the hydrocarbon risk calculator includes the BTEX, PAH, GRO, DRO, and RRO aromatic and aliphatic fractions in all risk calculations). The vapor concentrations used in this example assessment and associated vapor intrusion risks are summarized in Tables 11, 12, and 13. Tables 11 and 12 present the BTEX and GRO and DRO aromatic and aliphatic data. Table 13 presents PAH data. The NAPL equilibrium vapor concentrations used in Table 11 are based on the measured water concentrations from the carboy water and diffusion bag samples which were in equilibrium with NAPL, as described in the technical background document on groundwater sampling (Geosphere and CH2M HILL, 2006). The NAPL equilibrium vapor concentrations in Table 12 are based on the oil analyses as described in the technical background document on fuel characterization (Geosphere and CH2M HILL, 2006). In each table, the indoor target or risk-based vapor concentration is listed and compared to the vapor concentration in equilibrium with the NAPL as a “fraction of risk” value. The fraction of risk is calculated as the equilibrium vapor concentration divided by the risk-based vapor concentration. In addition, in Tables 11 and 12, the fraction of risk associated with a hypothetical site having an attenuation factor of .002 is calculated. As shown in Figure 2, this attenuation factor is the estimated attenuation factor for a hypothetical scenario of a NAPL source about 6 feet below the building foundation at a site with sandy soil. The comparison of the vapor concentrations in equilibrium with the NAPL to the allowable building concentrations indicate that for most of the fuels tested the BTEX, GRO aromatics, GRO aliphatics, DRO aromatics and DRO aliphatics fractions all have the potential to cause a vapor intrusion risk (Tables 11 and 12). However, when the attenuation of the equilibrium concentration is considered Tables 11 and 12 suggest the following.

At fresh gasoline and JP4 spill sites:

- Benzene, toluene, ethylbenzene, xylene, GRO aromatics and aliphatics and DRO aromatics have the potential to exceed risk-based criteria given an attenuation factor of 0.002
- DRO aliphatic criteria will likely not be exceeded given an attenuation factor of 0.002

At fresh Jet A and diesel #1 fuel spill sites:

- Benzene, toluene, ethylbenzene, and DRO aromatics and aliphatics have the potential to exceed risk-based criteria given an attenuation factor of 0.002

- Xylene and GRO aromatic and aliphatic criteria will likely not be exceeded given an attenuation factor of 0.002

At fresh diesel #2 fuel spill sites:

- Benzene, toluene, and ethylbenzene have the potential to exceed risk-based criteria given an attenuation factor of 0.002
- Xylene, GRO aromatic and aliphatic and DRO aromatic and aliphatic criteria may not be exceeded given an attenuation factor of 0.002

The PAH data (see Table 13) show that the PAH vapor concentrations in equilibrium with the fuel NAPLs did not exceed indoor air risk-based levels and, in fact, were several orders of magnitude below inhalation risk-based levels. These data indicate the PAH compounds should not be expected to present unacceptable vapor intrusion risks even at fresh spill sites and that measuring PAH soil gas concentrations is likely not necessary.

SECTION 5

Summary and SOCWG Recommendations

The SOCWG understands that the state of the science and state of the practice for assessing the vapor intrusion (or migration to indoor air) exposure route is evolving and that in concept the vapor intrusion route has the potential to pose unacceptable risks at many sites. Therefore, the SOCWG recommends the following:

- That the vapor intrusion route be included in the assessment of risk posed by fuel hydrocarbon spill sites in Alaska.
- That a research program be initiated to assess the impact of Arctic and Sub- Arctic building and soil conditions on the vapor intrusion route.

SECTION 6

References

Alaska Department of Environmental Conservation. 1998. *Guidance on Cleanup Standards Equations and Input Parameters*. September 16, 1998.

Alaska Department of Environmental Conservation. 1999. "Oil Spill and Hazardous Substances Pollution Control Regulations." *Alaska Administrative Code*. Title 18, Chapter 75. January 22, 1999.

Alaska Department of Environmental Conservation. 2002. Cumulative Risk Guidance.

Environmental Quality Management, Inc. 2004. User's Guide for Evaluating Subsurface Vapor Intrusion Into Buildings. A report prepared for the Environmental Protection Agency.

Geosphere and CH2M HILL. 2006a. *Three- and Four-Phase Partitioning of Petroleum Hydrocarbons and Human Health Risk Calculations Technical Background Report*. Report prepared for the SOCWG.

Geosphere and CH2M HILL. 2006b. *Hydrocarbon Characterization for Use in the Hydrocarbon Risk Calculator and Example Characterizations of Selected Alaskan Fuels, Technical Background Document*. Report prepared for the Alaska Statement of Cooperation Working Group (SOCWG).

Geosphere and CH2M HILL. 2006c. *Site Conditions Summary Report for Hydrocarbon Risk Calculations and Site Status Determination, Technical Background Document*. Report prepared for the Alaska Statement of Cooperation Working Group (SOCWG).

Geosphere and CH2M HILL. 2006d. *Proposed Environmental Site Closeout Concepts, Criteria, and Definitions, Technical Background Document*. Report prepared for the Alaska Statement of Cooperation Working Group (SOCWG).

Hers, Ian, R. Zapf-Gilje, P. Johnson, and L. Li. 2003. Evaluation of the Johnson and Ettinger Model of Indoor Air Quality. *Ground Water Monitoring and Remediation*, Vol. 23, No. 2, pages 119-133.

Total Petroleum Hydrocarbon (TPH) Criteria Working Group. 1996. *Selection of Representative TPH Fractions Based on Fate and Transport Considerations*. Volume 3. Amherst Scientific Publishing.

U.S. Environmental Protection Agency. 1996. *Soil Screening Guidance: Technical Background Document*.

Tables

Table 1 BTEX and PAH Compounds on the EPA Tier 1 Vapor Intrusion Screening List

Compound	Henry's Constant	Is compound sufficiently volatile?	Is Compound Sufficiently Toxic?
Benzene	0.228	Yes	Yes
Toluene	0.272	Yes	Yes
Ethylbenzene	0.323	Yes	Yes
Xylene	0.21	Yes	Yes
Naphthalene	1.98E-02	Yes	Yes
Acenaphthene	6.30E-03	Yes	Yes
Fluorene	2.61E-03	Yes	Yes
Anthracene	2.67E-03	Yes	Yes
Fluoranthene	6.60E-04	Yes	Yes
Pyrene	4.51E-04	Yes	Yes
Benzo (a) Anthracene	1.37E-04	Yes	Yes
Chrysene	3.88E-03	Yes	Yes
Benzo (b) fluoranthene	4.55E-03	Yes	Yes
Benzo (k) fluoranthene	3.40E-05	Yes	Yes
Benzo (a) pyrene	4.63E-05	Yes	Yes
Indeno (1,2,3-cd) pyrene	6.56E-05	Yes	Yes
Dibenz (a,h) anthracene	6.03E-07	No	Yes

Table 2 EPA Tier 2 Table of “Generic” BTEX and PAH Screening Concentrations

Compound	Basis of Target Concentrations: C= cancer ; NC = non-cancer	Target Air Concentrations			Target Shallow Soil Gas Concentration Corresponding to Target Indoor Air Concentration where Soil Gas to Indoor Air Attenuation Factor 0.1	Target Deep Soil Gas Concentration Corresponding to Target Indoor Air Concentration where Soil Gas to Indoor Air Attenuation Factor 0.01	Target Groundwater Concentration Corresponding to Target Indoor Air Concentration where Soil Gas to Indoor Air Attenuation Factor 0.001 and Partitioning Across the Water Table obeys Henry's Law (ug/L)
		C cancer R= 10-5 (ug/m ³)	C non-cancer HI = 1 (ug/m ³)	min of C cancer & C non-cancer (ug/m ³)			
Benzene	C	3.120	NA	3.1196581	31.197	311.966	140
Toluene	NC	NA	400	400	4000	40000	1500
Ethylbenzene	C	22.121	1000	22.121212	221.212	2212.121	700
Xylene	NC	NA	7000	7000	70000	700000	33000
Naphthalene	NC	NA	3	3	30	300	150
Acenaphthene	NC	NA	210	210	2100	21000	
Fluorene	NC	NA	140	140	1400	14000	
Anthracene	NC	NA	1100	1100	11000	110000	
Fluoranthene	NC	NA	140	140	1400	14000	
Pyrene	NC	NA	110	110	1100	11000	
Benzo (a) Anthracene	C	0.1159	NA	0.1159	1.159	11.59	
Chrysene	C	11.59	NA	11.59	115.873	1158.730	
Benzo (b) fluoranthene	C	0.1159	NA	0.1159	1.159	11.587	
Benzo (k) fluoranthene	C	1.159	NA	1.159	11.587	115.873	
Benzo (a) pyrene	C	0.00016	NA	0.00016	0.0016	0.016	
Indeno (1,2,3-cd) pyrene	C	0.1159	NA	0.1159	1.159	11.59	
Dibenz (a,h) anthracene	C	0.012	NA	0.012	NA	NA	NA

Table 3 EPA Tier 2 BTEX and PAH Screening Concentrations Based on Depth of Contamination and Soil Type

Compound	Basis of Target Concentrations: C= cancer ; NC = non-cancer	Target Air Concentrations	Target Soil Gas Concentration Corresponding to Attenuation Factors Listed Below (ug/m ³)				
		min of C cancer & C non-cancer (ug/m ³)					
Benzene	C	0.31197	2.00E-03	1.00E-03	7.00E-04	4.00E-04	2.00E-04
Toluene	NC	400	6.24E-04	3.12E-04	2.18E-04	1.25E-04	6.24E-05
Ethylbenzene	C	2.21212	8.00E-01	4.00E-01	2.80E-01	1.60E-01	8.00E-02
Xylene	NC	7000	4.42E-03	2.21E-03	1.55E-03	8.85E-04	4.42E-04
Naphthalene	NC	3.00	1.40E+01	7.00E+00	4.90E+00	2.80E+00	1.40E+00
Acenaphthene	NC	210	6.00E-03	3.00E-03	2.10E-03	1.20E-03	6.00E-04
Fluorene	NC	140	4.20E-01	2.10E-01	1.47E-01	8.40E-02	4.20E-02
Anthracene	NC	1100	2.80E-01	1.40E-01	9.80E-02	5.60E-02	2.80E-02
Fluoranthene	NC	140	2.20E+00	1.10E+00	7.70E-01	4.40E-01	2.20E-01
Pyrene	NC	110	2.80E-01	1.40E-01	9.80E-02	5.60E-02	2.80E-02
Benzo (a) Anthracene	C	0.011587	2.20E-01	1.10E-01	7.70E-02	4.40E-02	2.20E-02
Chrysene	C	1.158730	2.32E-05	1.16E-05	8.11E-06	4.63E-06	2.32E-06
Benzo (b) fluoranthene	C	0.011587	2.32E-03	1.16E-03	8.11E-04	4.63E-04	2.32E-04
Benzo (k) fluoranthene	C	0.011587	2.32E-05	1.16E-05	8.11E-06	4.63E-06	2.32E-06
Benzo (a) pyrene	C	0.000016	2.32E-04	1.16E-04	8.11E-05	4.63E-05	2.32E-05
Indeno (1,2,3-cd) pyrene	C	0.000016	3.24E-08	1.62E-08	1.14E-08	6.49E-09	3.24E-09
Indeno (1,2,3-cd) pyrene	C	0.011587	2.32E-05	1.16E-05	8.11E-06	4.63E-06	2.32E-06
Dibenz (a,h) anthracene	C	0.011587	NA	NA	NA	NA	NA

Compound	Basis of Target Concentrations: C= cancer ; NC = non-cancer	Target Air Concentrations	Target Groundwater Concentration Corresponding to Attenuation Factors Listed Below (ug/L)				
		min of C cancer & C non-cancer (ug/m ³)					
Benzene	C	0.311966	7.00E-04	5.00E-04	3.00E-04	2.00E-04	1.00E-04
Toluene	NC	400	2.00E+01	2.70E+01	4.60E+01	6.90E+00	1.42E+02
Ethylbenzene	C	2.212121	2.10E+03	2.90E+03	4.90E+03	7.40E+03	1.50E+04
Xylene	NC	7000	2.20E+02	3.00E+02	5.10E+02	7.60E+02	1.20E+04
Naphthalene	NC	3.00	3.20E+04	4.50E+04	7.40E+04	1.10E+05	
Acenaphthene	NC	210	2.20E+02	3.00E+02	5.10E+02	7.60E+02	1.50E+03
Fluorene	NC	140					
Anthracene	NC	1100					
Fluoranthene	NC	140					
Pyrene	NC	110					
Benzo (a) Anthracene	C	0.011587					
Chrysene	C	1.158730					
Benzo (b) fluoranthene	C	0.011587					
Benzo (k) fluoranthene	C	0.0115873					
Benzo (a) pyrene	C	0.000016					
Indeno (1,2,3-cd) pyrene	C	0.011587					
Dibenz (a,h) anthracene	C	0.011587	NA	NA	NA	NA	NA

Table 4 Uncertainty and Sensitivity of Key Parameters for the Vapor Intrusion Route (from Environmental Quality Management, 2004)

Input Parameter	Parameter Uncertainty Or Variability	Shallower Contamination Building Underpressurized	Parameter Sensitivity		Deeper Contamination Building Not Underpressurized
			Deeper Contamination Building Underpressurized	Shallower Contamination Building Not Underpressurized	
Soil Total Porosity (n)	Low	Low	Low	Low	Low
Soil Water-filled Porosity (θ_w)	Moderate to High	Low to Moderate	Moderate to High	Moderate to High	Moderate to High
Capillary Zone Water-filled Porosity ($\theta_{w,cz}$)	Moderate to High	Moderate to High	Moderate to High	Moderate to High	Moderate to High
Thickness of Capillary Zone (L_{cz})	Moderate to High	Moderate to High	Moderate to High	Moderate to High	Moderate to High
Soft Dry Bulk Density (ρ_s)	Low	Low	Low	Low	Low
Average Vapor Flowrate into a Building (Q_{soil})	High	Moderate to High	Low to Moderate	N/A	N/A
Soil Vapor Permeability (K_v)	High	Moderate to High	Low to Moderate	N/A	N/A
Soil to Building Pressure Differential (ΔP)	Moderate	Moderate	Low to Moderate	N/A	N/A
Henry's Law Constant (for single chemical) (H)	Low to Moderate	Low to Moderate	Low to Moderate	Low to Moderate	Low to Moderate
Diffusivity in Air (D_A)	Low	Low	Low	Low	Low
Indoor Air Exchange Rate (ER)	Moderate	Moderate	Moderate	Moderate	Moderate
Enclosed Space Height (H_B)	Moderate	Moderate	Moderate	Moderate	Moderate
Area of Enclosed Space Below Grade (A_B)	Low to Moderate	Low to Moderate	Low to Moderate	Low to Moderate	Low to Moderate
Depth Below Grade to Bottom of Enclosed Space (L_T)	Low	Low	Low	Low	Low
Crack-to-Total Area Ratio (η)	High	Low	Low	Moderate to High	Low to Moderate
Enclosed Space Floor Thickness (L_{crack})	Low	Low	Low	Low	Low

Table 5 Example Soil Types and Soil Property Values (from Environmental Quality Management, 2004)

U.S. Soil Conservation Service (SCS) Soil Texture	Saturated		Unsaturated Zone				Capillary Transition Zone		
	Water Content Total Porosity θ_s (cm ³ /cm ³)	Residual Water Content θ_r (cm ³ /cm ³)	Water-Filled Porosity				Saturated Water Content Total Porosity θ_s (cm ³ /cm ³)	$\theta_{w,cap}$ @ air-entry	Height Cap Zone Fetter (94) (cm)
			Mean or Typical (FC _{150bar} + θ_r)/2 $\theta_{w,unsat}$ (cm ³ /cm ³)	Range $\theta_{w,unsat}$ (cm ³ /cm ³)	Conservative $\theta_{w,unsat}$ (cm ³ /cm ³)	Modeled $\theta_{w,unsat}$ (cm ³ /cm ³)			
Clay	0.459	0.098	0.215	0.099-0.33	0.098	0.215	0.459	0.412	81.5
Clay Loam	0.442	0.079	0.168	0.079-0.26	0.079	0.168	0.442	0.375	46.9
Loam	0.399	0.061	0.148	0.061-0.24	0.061	0.148	0.399	0.332	37.5
Loamy Sand	0.39	0.049	0.076	0.049-0.1	0.049	0.076	0.39	0.303	18.8
Silt	0.489	0.05	0.167	0.05-0.28	0.050	0.167	0.489	0.382	163.0
Silt Loam	0.439	0.066	0.180	0.066-0.3	0.066	0.180	0.439	0.349	68.2
Silty Clay	0.481	0.111	0.216	0.11-0.32	0.111	0.216	0.481	0.424	192.0
Silty Clay Loam	0.482	0.09	0.198	0.09-0.31	0.090	0.198	0.482	0.399	133.9
Sand	0.375	0.053	0.054	0.053-0.056	0.053	0.054	0.375	0.253	17.0
Sandy Clay	0.385	0.117	0.197	0.117-0.28	0.117	0.197	0.385	0.355	30.0
Sandy Clay Loam	0.384	0.063	0.146	0.063-0.23	0.063	0.146	0.384	0.333	25.9
Sandy Loam	0.387	0.039	0.103	0.039-0.17	0.039	0.103	0.387	0.320	25.0
Loamy Sand	0.39	0.049	0.076	0.049-0.1	0.049	0.076	0.39	0.303	18.8

Table 6 Range of Model Input Values for Selected Parameters (from Environmental Quality Management, 2004)

Input parameter	Practical range of values	Default value
Soil water-filled porosity (θ_w)	0.04 – 0.33 cm ³ /cm ^{3a}	Soil dependent see Table 10
Soil vapor permeability (k_v)	10 ⁻⁶ – 10 ⁻¹² cm ^{2b,c}	10 ⁻⁸ cm ^{2d}
Soil-building pressure differential (ΔP)	0 – 20 Pa ³	4 Pa ^f
Media initial concentration (C_R, C_w)	User-defined	NA
Depth to bottom of soil contamination (L_b)	User-defined	NA
Depth to top of concentration (L_T)	User-defined	NA
Floor-wall seam gap (w)	0.05 – 1.0 cm ^e	0.1 cm ^e
Soil organic carbon fraction (f_{oc})	0.001 – 0.006 ^a	0.002 ^a
Indoor air exchange rate (ER)	0.18 – 1.26 (H ⁻¹) ^g	0.25 (H ⁻¹) ^{g,h}
Soil total porosity (n)	0.34 – 0.53 cm ³ /cm ^{3a}	0.43 cm ³ /cm ^{3a}
Soil dry bulk density (ρ_b)	1.25 – 1.75 g/cm ^{3a}	1.5 g/cm ^{3a}

^aU.S. EPA (1996a and b).

^bJohnson and Ettinger (1991).

^cNazaroff (1988).

^dBased on transition point between diffusion and convection dominated transport from Johnson and Ettinger (1991).

^eEaton and Scott (1984); Loureiro et al. (1990).

^fLoureiro et al. (1990); Grimsrud et al. (1983).

^gKoontz and Rector (1995).

^hParker et al. (1990).

ⁱU.S. DOE (1995).

Table 7 Example Building Input Parameter Values (from Environmental Quality Management, 2004)

Input Parameter	Units	Fixed or Variable	Typical or Mean Value	Range	Conservative Value	Default Value
Total Porosity	cm ³ /cm ³	Fixed	Specific to soil texture, see Table 10			
Unsaturated Zone Water-filled Porosity	cm ³ /cm ³	Variable	Specific to soil texture, see Table 10			
Capillary Transition zone Water-filled Porosity	cm ³ /cm ³	Fixed	Specific to soil texture, see Table 10			
Capillary Transition Zone height	cm ³ /cm ³	Fixed	Specific to soil texture, see Table 10			
Q _{cell}	L/min	Variable	Specific to soil texture, see Table 10			
Soil air permeability	m ²	Variable	Specific to soil texture, see Table 10			
Building Depressurization	Pa	Variable	4	0-15	15	N/A
Henry's law constant (for single chemical)	-	Fixed	Specific to chemical, see Appendix B			
Free-Air Diffusion Coefficient (single chemical)	-	Fixed	Specific to chemical, see Appendix B			
Building Air exchange Rate	hr ⁻¹	Variable	0.5	0.1-1.5	0.1	0.25
Building Mixing height – Basement scenario	m	Variable	3.66	2.44-4.88	2.44	3.66
Building Mixing height – Slab-on-grade scenario	m	Variable	2.44	2.13-3.05	2.13	2.44
Building Footprint Area – Basement Scenario	m ²	Variable	120	80-200+	80	100
Building Footprint Area – Slab-on-Grade Scenario	m ²	Variable	120	80-200+	80	100
Subsurface Foundation area – Basement Scenario	m ²	Variable	208	152-313+	152	180
Subsurface Foundation area – Slab-on-Grade Scenario	m ²	Fixed	127	85-208+	85	106
Depth to Base of Foundation – Basement Scenario	m	Fixed	2	N/A	N/A	2
Depth to Base of Foundation – Slab-on-Grade Scenario	m	Fixed	0.15	N/A	N/A	0.15
Perimeter Crack Width	mm	Variable	1	0.5-5	5	1
Building Crack ratio – Slab-on-Grade Scenario	dimensionless	Variable	0.00038	0.00019-0.0019	0.0019	3.77 x 10 ⁻⁴
Building Crack ratio – Basement Scenario	dimensionless	Variable	0.0002	0.0001-0.001	0.001	2.2 x 10 ⁻⁴
Crack Dust Water-Filled Porosity	cm ³ /cm ³	Fixed	Dry	N/A	N/A	Dry
Building Foundation Slab Thickness	m	Fixed	0.1	N/A	N/A	0.1

Table 8 Effect on Building Concentration from an Increase in Input Parameter Values

Input parameter	Change in parameter value	Effect on building concentration
Soil water-filled porosity (θ_w)	Increase	Decrease
Soil vapor permeability (k_v)	Increase	Increase
Soil-building pressure differential (ΔP)	Increase	Increase
Media initial concentration (C_R, C_w) ^a	Increase	Increase
Depth to bottom of soil contamination (L_b) ^b	Increase	Increase
Depth to top of concentration (L_T)	Increase	Decrease
Floor-wall seam gap (w)	Increase	Increase
Soil organic carbon fraction (f_{oc})	Increase	Decrease
Indoor air exchange rate (ER)	Increase	Decrease
Building volume ^c ($L_B \times W_B \times H_B$)	Increase	Decrease
Soil total porosity (n)	Increase	Increase
Soil dry bulk density (ρ_b)	Increase	Decrease

^a This parameter is applicable only when forward-calculating risk.

^b Applicable only to advanced model for soil contamination.

^c Used with building air exchange rate to calculate building ventilation rate.

Table 9 Example Soil and Building Parameters Data Entry Page from the Hydrocarbon Risk Calculator

Table X	Migration to Indoor Air-- Data Entry			FAA Strawberry Point Station			Shop & Generator Bldg			Page 2		
NAPL source area soil gas concentrations calculated by the 4-phase calculator. Attenuation factor "alpha" calculated by the Johnson & Ettinger model. Incremental risk posed by NAPL source area soil gas concentrations via the migration to indoor air pathway shown here and entered into the cumulative risk calculations.												
Site Specific and/or Field Data in Yellow Highlighted Cells												
Soil Properties:	Top Layer immediately below slab (not contaminated)	Middle Layer (not contaminated)	Bottom Layer (not contaminated)	Building Properties:	input value	default input values: basement	default input values: slab on grade			Human Health Exposure Criteria		
bulk density (lbs/ft ³)	94	100	105	Lb = length of building (cm)	1000	1000	1000			Residential	Industrial	
bulk density (g/cm ³)	1.506410256	1.602564103	1.682692308	Wb = width of building (cm)	1000	1000	1000	Acrack= area of total cracks (cm ²) = Xcrack* Wcrack = Ab/n	400	TCR=	1.00E-05	1.00E-05
specific gravity of solids	2.65	2.65	2.65	Hb = height of building (cm)	366	366	244	Xcrack = floor -wall seam perimeter (cm)	4000	THQ= target hazard quotient (e.g. 1.0)	1	1
porosity	0.431543299	0.395258829	0.365021771	ER = air exchange rate (1/hr)	0.25	0.25		u = viscosity of air (g/cm-sec)	1.75E-04	ATc= averaging time carcinogen (days), (=70 years)	25,550	25,550
moisture content (% by weight)	16.11	12	14	Lf = depth below grade of bottom of floor slab or basement (cm)	200	200	15	Zcrack = crack depth below grade (cm)	200	ATnc= averaging time non-carcinogen	30	30
foc	0.00172	0.00172	0.00172	Wcrack = floor -wall seam crack width (cm)	0.1			equation 16 r crack= n/(Ab/Xcrack)	0.1	EF= exposure frequency (350 days/year)	350	250
water filled porosity	0.242682692	0.192307692	0.235576923	Lcrack = enclosed space foundation thickness or slab thickness (cm)	10	10	10	n = Acrack/Ab (0<n<=1)	0.000222222	ED= exposure duration (30 years)	30	25
air filled porosity	0.188860607	0.202951137	0.129444848	delta P = pressure differential between building and soil (g/cm-s ²)	40	=4 Pa	typical conservative values = 4 or 5; max range = 0 to 20	equation 14 Q building=building ventilation rate (cm ³ /sec) = (Lb*Wb*Hb*ER)/3,600s/h	2.54E+04	C cancer =	[(TCR*ATc)/(EF*ED*URF)]	
layer thickness (ft)	8	3	3	kv = soil vapor permeability= top soil layer (cm ²)	1.00E-08	1.00E-08		equation 14 Q building=building ventilation rate (cm ³ /sec; over ride calculated value--optional)		C non-cancer =	(TQH*Rfc*1000ug/mg)	
layer thickness (cm)	243.84	91.44	91.44	Ab= surface area of enclosed space below grade (cm ²)	1.80E+06	=area of basement walls+ basement floor... or area of slab		equation 15 Q soil = (2* pi * delta P * kv * Xcrack)/u ln (2 Zcrack/ r crack)	6.91E+00			
Ls = Total depth from ground surface to contaminant (ft)	14	Ls soil gas reading depth (cm)	426.72	Q building =building ventilation rate (cm ³ /sec)	25416.66667							
kv = soil vapor permeability (cm ²)	1.00E-08	1.00E-08	1.00E-08	Lr = total source-building separation distance (cm)	226.72							

Table 10 Example of the Migration to Indoor Air Risk Characterization Output from the Hydrocarbon Risk Calculator

Table X		Migration to Indoor Air Vapor Inhalation Levels					
Page 6	FAA Strawberry Point Station			Shop & Generator Bldg			
1	2	3	4	5	6	7	8
Compounds	Vapor Concentration in Sample (ug/m ³)	Building Vapor Concentration given site conditions (ug/m ³)	Residential Land Use Target Building Vapor Concentration when HQ=1 or Target Risk =10 ⁻⁵ (ug/m ³)	Residential Land Use Hazard Quotient or Fraction of Risk Based Target Concentration (values greater than 1 exceed the risk based target)	Residential Land Use check for compliance with risk levels (0= in compliance; 1= not in compliance)	Industrial Land Use Hazard Quotient or Fraction of Risk Based Target Concentration (values greater than 1 exceed the risk based target)	Industrial Land Use check for compliance with risk levels (0= in compliance; 1= not in compliance)
Benzene	22.573	0.0036	3.1197	0.0012	0	6.91E-04	0
Toluene	164.	0.0261	400.	6.26E-05	0	3.73E-05	0
Ethylbenzene	32.8294	0.0049	22.1212	2.22E-04	0	1.32E-04	0
Xylene	1,027.	0.1489	7,000.	2.04E-05	0	1.21E-05	0
GRO Aromatics	11,289.	1.9056	400.	0.0046	0	0.0027	0
DRO Aromatics	35,225.	5.9601	200.	0.0286	0	0.017	0
RRO Aromatics	1,479.	0.2523	NA	NA	0	NA	0
GRO Aliphatics	602.	0.1058	18,400.	5.51E-06	0	3.28E-06	0
DRO Aliphatics	471.	0.1038	1,000.	9.95E-05	0	5.92E-05	0
RRO Aliphatics	276,437.	46.5344	NA	NA	0	NA	0
Naphthalene	ND	ND	3.	ND	0	ND	0
Acenaphthene	897.	0.1511	210.	6.90E-04	0	4.11E-04	0
Fluorene	1,095.	0.1843	140.	0.0013	0	7.52E-04	0
Anthracene	5.0529	8.51E-04	1,100.	7.41E-07	0	4.41E-07	0
Fluoranthene	203.	0.0342	140.	2.34E-04	0	1.39E-04	0
Pyrene	15,037.	2.5312	110.	0.0221	0	0.0131	0
Benzo (a) Anthracene	1.54E-05	2.16E-09	0.1159	1.86E-08	0	1.11E-08	0
Chrysene	2.31E-06	3.25E-10	11.5873	2.80E-11	0	1.67E-11	0
Benzo (b) fluoranthene	6.09E-07	9.75E-11	0.1159	8.42E-10	0	5.01E-10	0
Benzo (k) fluoranthene	2.10E-07	3.39E-11	1.1587	2.92E-11	0	1.74E-11	0
Benzo (a) pyrene	8.08E-08	1.70E-11	1.62E-04	1.05E-07	0	6.24E-08	0
Indeno (1,2,3-cd) pyrene	2.25E-10	5.15E-14	0.1159	4.44E-13	0	2.64E-13	0
Dibenz (a,h) anthracene	3.68E-09	9.61E-13	0.0116	8.29E-11	0	4.93E-11	0
Carcinogenic Cumulative Risk			ethylbenzene as carcinogen	0.0014	0	6.91E-04	0
noncarcinogenic Cumulative Risk				0.0243	0	0.0145	0

Values shown in the fifth and eighth columns are the normalized fraction of the risk based level, and not the carcinogenic risk level. The fraction of risk multiplied by 10⁻⁵ equals the carcinogenic risk level for the carcinogenic compounds.

Table 11 BTEX, GRO & DRO Vapor Concentrations in Equilibrium with the NAPL of Selected Fuels and Fraction of Risk Associated with Vapor Concentrations (from measured water concentrations)

Aromatic Fractions	Building Target Air Concentration (min of C cancer & C non-cancer; ug/m ³)	Sample #6 Regular Gasoline			Sample #3 JP4			Sample #4 DF1 Diesel Fuel			Sample #9 Jet A			Sample #10 Diesel Fuel			Sample #12 DF2 Diesel Fuel			Average Jet A & Diesel Fuel (DF1 & DF2) Dissolved Concentration		
		equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002
Benzene	3.120	2.9E+07	9.2E+06	1.8E+04	4.7E+06	1.5E+06	3.0E+03	2.0E+05	6.5E+04	1.3E+02	1.1E+05	3.6E+04	7.2E+01	1.3E+05	4.1E+04	8.2E+01	1.5E+05	4.8E+04	9.6E+01	1.5E+05	4.8E+04	9.5E+01
Toluene	400	2.9E+07	7.2E+04	1.4E+02	4.0E+06	1.0E+04	2.0E+01	5.7E+05	1.4E+03	2.8E+00	4.1E+05	1.0E+03	2.1E+00	4.1E+05	1.0E+03	2.1E+00	2.5E+05	6.4E+02	1.3E+00	4.1E+05	1.0E+03	2.1E+00
Ethylbenzene	22.121	8.8E+05	4.0E+04	8.0E+01	1.9E+05	8.5E+03	1.7E+01	1.0E+05	4.6E+03	9.2E+00	8.3E+04	3.7E+03	7.5E+00	7.2E+04	3.2E+03	6.5E+00	2.0E+04	8.8E+02	1.8E+00	6.9E+04	3.1E+03	6.2E+00
Xylene	7000	5.8E+06	8.3E+02	1.7E+00	1.2E+06	1.6E+02	3.3E-01	8.0E+05	1.1E+02	2.3E-01	6.2E+05	8.9E+01	1.8E-01	5.2E+05	7.4E+01	1.5E-01	1.3E+05	1.9E+01	3.8E-02	5.2E+05	7.4E+01	1.5E-01
C ₉ -C ₁₀	400	8.4E+05	2.1E+03	4.2E+00	1.8E+05	4.4E+02	8.8E-01	7.9E+05	2.0E+03	3.9E+00	9.2E+05	2.3E+03	4.6E+00	5.1E+05	1.3E+03	2.5E+00	7.4E+04	1.8E+02	3.7E-01	5.7E+05	1.4E+03	2.9E+00
C ₁₀ -C ₁₂	200	1.4E+05	6.9E+02	1.4E+00	6.5E+04	3.3E+02	6.5E-01	1.8E+05	9.0E+02	1.8E+00	2.4E+05	1.2E+03	2.4E+00	1.4E+05	7.2E+02	1.4E+00	3.0E+04	1.5E+02	3.0E-01	1.5E+05	7.4E+02	1.5E+00
C ₁₂ -C ₁₆	200	0.0E+00	0.0E+00	0.0E+00	3.1E+04	1.6E+02	3.1E-01	8.7E+04	4.3E+02	8.7E-01	6.3E+04	3.1E+02	6.3E-01	3.7E+04	1.8E+02	3.7E-01	4.3E+04	2.1E+02	4.3E-01	5.7E+04	2.9E+02	5.7E-01
C ₁₆ -C ₂₁	200	0.0E+00	0.0E+00	0.0E+00	8.3E+02	4.2E+00	8.3E-03	1.7E+03	8.5E+00	1.7E-02	6.5E+02	3.3E+00	6.5E-03	2.6E+03	1.3E+01	2.6E-02	1.3E+04	6.4E+01	1.3E-01	4.4E+03	2.2E+01	4.4E-02
C ₂₁ -C ₃₅	NA	0.0E+00	NA	NA	8.8E+00	NA	NA	1.1E+01	NA	NA	1.1E+01	NA	NA	8.8E+00	NA	NA	8.8E+00	NA	NA	9.9E+00	NA	NA
Sum of Aromatics		6.5E+07	NA	NA	1.0E+07	NA	NA	2.7E+06	NA	NA	2.4E+06	NA	NA	1.8E+06	NA	NA	7.2E+05	NA	NA	1.9E+06	NA	NA
Aliphatic Fractions																						
C ₅ -C ₆	18400	1.3E+08	7.0E+03	1.4E+01	1.4E+08	7.4E+03	1.5E+01	1.8E+05	9.8E+00	2.0E-02	4.8E+05	2.6E+01	5.2E-02	4.8E+05	2.6E+01	5.2E-02	3.7E+05	2.0E+01	4.0E-02	3.8E+05	2.1E+01	4.1E-02
C ₆ -C ₈	18400	7.4E+09	4.0E+05	8.0E+02	1.6E+09	8.7E+04	1.7E+02	1.0E+08	5.6E+03	1.1E+01	7.2E+07	3.9E+03	7.8E+00	7.5E+07	4.1E+03	8.2E+00	5.8E+07	3.1E+03	6.3E+00	7.7E+07	4.2E+03	8.4E+00
C ₈ -C ₁₀	18400	0.0E+00	0.0E+00	0.0E+00	9.4E+07	5.1E+03	1.0E+01	8.3E+07	4.5E+03	9.1E+00	7.1E+07	3.9E+03	7.7E+00	7.0E+06	3.8E+02	7.6E-01	2.3E+07	1.2E+03	2.5E+00	4.6E+07	2.5E+03	5.0E+00
C ₁₀ -C ₁₂	1000	3.8E+08	3.8E+05	7.5E+02	2.3E+07	2.3E+04	4.6E+01	2.3E+08	2.3E+05	4.6E+02	3.5E+08	3.5E+05	6.9E+02	1.7E+08	1.7E+05	3.4E+02	1.6E+07	1.6E+04	3.2E+01	1.9E+08	1.9E+05	3.8E+02
C ₁₂ -C ₁₆	1000	0.0E+00	0.0E+00	0.0E+00	6.5E+07	6.5E+04	1.3E+02	4.5E+07	4.5E+04	9.1E+01	5.9E+07	5.9E+04	1.2E+02	8.5E+06	8.5E+03	1.7E+01	1.9E+08	1.9E+05	3.9E+02	7.7E+07	7.7E+04	1.5E+02
C ₁₆ -C ₂₁	1000	0.0E+00	0.0E+00	0.0E+00	1.0E+08	1.0E+05	2.0E+02	1.3E+08	1.3E+05	2.5E+02	1.3E+08	1.3E+05	2.5E+02	1.0E+08	1.0E+05	2.0E+02	2.7E+09	2.7E+06	5.5E+03	7.7E+08	7.7E+05	1.5E+03
C ₂₁ -C ₃₅	NA	0.0E+00	NA	NA	7.6E+09	NA	NA	9.5E+09	NA	NA	9.5E+09	NA	NA	7.6E+09	NA	NA	7.6E+09	NA	NA	8.5E+09	NA	NA
Sum of Aliphatics		7.9E+09	NA	NA	9.6E+09	NA	NA	1.0E+10	NA	NA	1.0E+10	NA	NA	8.0E+09	NA	NA	1.1E+10	NA	NA	9.7E+09	NA	NA
Total Hydrocarbon	NA	7.9E+09	NA	NA	9.6E+09	NA	NA	1.0E+10	NA	NA	1.0E+10	NA	NA	8.0E+09	NA	NA	1.1E+10	NA	NA	9.7E+09	NA	NA
GRO aromatics (C ₅ to C ₁₀)	NA	6.5E+07	NA	NA	1.0E+07	NA	NA	2.5E+06	NA	NA	2.1E+06	NA	NA	1.6E+06	NA	NA	6.3E+05	NA	NA	1.7E+06	NA	NA
GRO aliphatics (C ₅ to C ₁₀)	18400	7.5E+09	4.1E+05	8.1E+02	1.8E+09	9.9E+04	2.0E+02	1.9E+08	1.0E+04	2.0E+01	1.4E+08	7.8E+03	1.6E+01	8.3E+07	4.5E+03	9.0E+00	8.1E+07	4.4E+03	8.8E+00	1.2E+08	6.7E+03	1.3E+01
DRO aromatics (C ₁₀ to C ₂₁)	200	1.4E+05	6.9E+02	1.4E+00	9.7E+04	4.9E+02	9.7E-01	2.7E+05	1.3E+03	2.7E+00	3.0E+05	1.5E+03	3.0E+00	1.8E+05	9.2E+02	1.8E+00	8.6E+04	4.3E+02	8.6E-01	2.1E+05	1.0E+03	2.1E+00
DRO aliphatics (C ₁₀ to C ₂₁)	1000	3.8E+08	3.8E+05	7.5E+02	1.9E+08	1.9E+05	3.8E+02	4.0E+08	4.0E+05	8.1E+02	5.3E+08	5.3E+05	1.1E+03	2.8E+08	2.8E+05	5.6E+02	2.9E+09	2.9E+06	5.9E+03	1.0E+09	1.0E+06	2.1E+03
RRO (C ₂₁ to C ₃₅)	NA	0.0E+00	NA	NA	7.6E+09	NA	NA	9.5E+09	NA	NA	9.5E+09	NA	NA	7.6E+09	NA	NA	7.6E+09	NA	NA	8.5E+09	NA	NA

Table 12 BTEX, GRO & DRO Vapor Concentrations in Equilibrium with the NAPL of Selected Fuels and Fraction of Risk Associated with Vapor Concentrations (Calculated from Oil Analyses)

Aromatic Fractions	Building Target Air Concentration (min of C cancer & C non-cancer, ug/m ³)	Sample #1 Regular Gas			Sample #2 Premium Gas			Sample #3 JP4			Sample #4 DF1 (Jet A)			Sample #5 DF2			Sample #6 Regular Gas			Sample #7 Premium Gas			Sample #8 Aviation Gas			Sample #9 Jet A			Sample #10 DF			Sample #11 Jet A			Sample #12 DF2				
		equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002	equilibrium vapor concentration (ug/m ³)	fraction of risk posed by equilibrium vapor concentration	fraction of risk posed given an attenuation factor of .002					
Benzene	3.120	1.6E+07	5.2E+06	1.0E+04	1.4E+07	4.6E+06	9.3E+03	3.5E+06	1.1E+06	2.2E+03	2.5E+05	8.1E+04	1.6E+02	7.8E+04	2.5E+04	5.0E+01	2.3E+07	7.4E+06	1.5E+04	2.5E+07	7.9E+06	1.6E+04	3.4E+05	1.1E+05	2.2E+02	1.1E+05	3.4E+04	6.8E+01	2.1E+05	6.6E+04	1.3E+02	7.5E+04	2.4E+04	4.8E+01	2.0E+05	6.5E+04	1.3E+02		
Toluene	400	1.8E+07	4.5E+04	9.1E+01	2.2E+07	5.6E+04	1.1E+02	2.6E+06	6.6E+03	1.3E+01	6.3E+05	1.6E+03	3.1E+00	1.7E+05	4.2E+02	8.4E-01	2.1E+07	5.2E+04	1.0E+02	2.6E+07	6.4E+04	1.3E+02	2.3E+07	5.9E+04	1.2E+02	3.4E+05	8.4E+02	1.7E+00	6.2E+05	1.6E+03	3.1E+00	6.3E+05	1.6E+03	3.2E+00	3.3E+05	8.1E+02	1.6E+00		
Ethylbenzene	22.121	8.7E+05	3.9E+04	7.9E+01	1.1E+06	5.0E+04	9.9E+01	1.5E+05	6.6E+03	1.3E+01	9.2E+04	4.1E+03	8.3E+00	1.8E+04	8.4E+02	1.7E+00	8.3E+05	3.7E+04	7.5E+01	1.1E+06	4.8E+04	9.6E+01	1.2E+04	5.4E+02	1.1E+00	7.3E+04	3.3E+03	6.6E+00	9.8E+04	4.4E+03	8.9E+00	1.6E+05	7.3E+03	1.5E+01	2.5E+04	1.1E+03	2.2E+00		
Xylene	7000	4.9E+06	7.0E+02	1.4E+00	6.2E+06	8.9E+02	1.8E+00	8.4E+05	1.2E+02	2.4E-01	6.6E+05	9.5E+01	1.9E-01	1.1E+05	1.6E+01	3.2E-02	5.1E+06	7.3E+02	1.5E+00	6.6E+06	9.5E+02	1.9E+00	6.7E+04	9.5E+00	1.9E-02	5.1E+05	7.2E+01	1.4E-01	6.7E+05	9.5E+01	1.9E-01	1.4E+06	2.0E+02	4.0E-01	1.6E+05	2.3E+01	4.5E-02		
C ₉ -C ₁₀	400	1.6E+06	3.9E+03	7.8E+00	1.9E+06	4.7E+03	9.4E+00	8.7E+04	2.2E+02	4.4E-01	3.7E+04	9.1E+01	1.8E-01	1.2E+03	2.9E+00	5.9E-03	1.6E+06	4.1E+03	8.2E+00	1.5E+06	3.8E+03	7.6E+00	7.4E+03	1.9E+01	3.7E-02	8.2E+03	2.0E+01	4.1E-02	2.3E+04	5.9E+01	1.2E-01	6.4E+04	1.6E+02	3.2E-01	3.2E+02	7.9E-01	1.6E-03		
C ₁₀ -C ₁₂	200	2.5E+05	1.3E+03	2.5E+00	2.9E+05	1.4E+03	2.9E+00	6.9E+04	3.5E+02	6.9E-01	1.5E+05	7.7E+02	1.5E+00	4.8E+03	2.4E+01	4.8E-02	1.0E+05	5.0E+02	1.0E+00	1.4E+05	7.0E+02	1.4E+00	2.5E+03	1.2E+01	2.5E-02	8.5E+04	4.2E+02	8.5E-01	1.1E+05	5.3E+02	1.1E+00	2.2E+05	1.1E+03	2.2E+00	2.8E+03	1.4E+01	2.8E-02		
C ₁₂ -C ₁₆	200	2.0E+03	9.9E+00	2.0E-02	1.6E+03	7.9E+00	1.6E-02	2.5E+04	1.3E+02	2.5E-01	5.5E+04	2.7E+02	5.5E-01	9.8E+03	4.9E+01	9.8E-02	6.7E+02	3.3E+00	6.7E-03	9.8E+02	4.9E+00	9.8E-03	0.0E+00	0.0E+00	0.0E+00	3.5E+04	1.7E+02	3.5E-01	4.2E+04	2.1E+02	4.2E-01	6.3E+04	3.2E+02	6.3E-01	1.2E+04	6.0E+01	1.2E-01		
C ₁₆ -C ₂₁	200	1.0E+00	5.0E-03	1.0E-05	5.1E-01	2.5E-03	5.1E-06	6.8E+02	3.4E+00	6.8E-03	1.5E+03	7.6E+00	1.5E-02	1.0E+04	5.1E+01	1.0E-01	1.3E+01	1.5E+03	6.5E-02	1.3E-04	1.3E+01	1.0E+04	6.3E-02	1.3E-04	0.0E+00	0.0E+00	0.0E+00	6.5E+02	3.3E+00	6.5E-03	4.1E+03	2.0E+01	4.1E-02	7.7E+02	3.9E+00	7.7E-03	9.1E+03	4.6E+01	9.1E-02
C ₂₁ -C ₂₅	NA	3.7E-04	NA	NA	2.3E-04	NA	NA	4.7E-04	NA	NA	3.1E-04	NA	NA	1.2E-07	NA	NA	9.9E-05	NA	NA	1.1E-04	NA	NA	4.3E-07	NA	NA	3.4E-06	NA	NA	3.7E-02	NA	NA	5.2E-04	NA	NA	1.7E-01	NA	NA		
Sum of Aromatics		4.2E+07	NA	NA	4.6E+07	NA	NA	7.3E+06	NA	NA	1.9E+06	NA	NA	4.0E+05	NA	NA	5.2E+07	NA	NA	6.0E+07	NA	NA	2.4E+07	NA	NA	1.1E+06	NA	NA	1.8E+06	NA	NA	2.6E+06	NA	NA	7.4E+05	NA	NA		
Aliphatic Fractions																																							
C ₇ -C ₈	18400	4.8E+08	2.6E+04	5.2E+01	4.2E+08	2.3E+04	4.6E+01	1.2E+08	6.3E+03	1.3E+01	1.2E+06	6.5E+01	1.3E-01	8.5E+05	4.6E+01	9.2E-02	3.5E+08	1.9E+04	3.8E+01	2.7E+08	1.5E+04	2.9E+01	2.5E+08	1.3E+04	2.7E+01	1.2E+06	6.3E+01	1.3E-01	1.5E+06	8.3E+01	1.7E-01	4.0E+05	2.2E+01	4.4E-02	1.5E+06	8.1E+01	1.6E-01		
C ₉ -C ₁₀	18400	1.5E+07	8.0E+02	1.6E+00	5.2E+06	2.8E+02	5.7E-01	8.3E+07	4.5E+03	9.0E+00	3.8E+06	2.1E+02	4.2E-01	3.9E+05	2.1E+01	4.2E-02	2.3E+07	1.3E+03	2.5E+00	7.4E+06	3.9E+02	8.0E-01	7.3E+07	4.0E+03	7.9E+00	3.0E+06	1.6E+02	3.3E-01	3.0E+06	1.6E+02	3.2E-01	2.4E+06	1.3E+02	2.6E-01	8.0E+05	4.3E+01	8.7E-02		
C ₁₀ -C ₁₂	18400	4.1E+06	2.2E+02	4.4E-01	3.8E+06	2.0E+02	4.1E-01	1.3E+07	7.0E+02	1.4E+00	4.1E+06	2.2E+02	4.4E-01	3.4E+05	1.8E+01	3.7E-02	7.7E+06	4.2E+02	8.3E-01	8.2E+06	4.5E+02	8.9E-01	1.5E+07	8.0E+02	1.6E+00	2.8E+06	1.5E+02	3.1E-01	3.3E+06	1.8E+02	3.6E-01	4.3E+06	2.3E+02	4.7E-01	5.0E+05	2.7E+01	5.4E-02		
C ₁₂ -C ₁₆	1000	2.5E+05	2.5E+02	5.0E-01	2.8E+05	2.8E+02	5.7E-01	2.0E+05	2.0E+02	3.9E-01	1.3E+06	1.3E+03	2.6E+00	1.2E+05	1.2E+02	2.5E-01	1.2E+05	1.2E+02	2.5E-01	2.2E+05	2.2E+02	4.3E-01	8.6E+03	8.6E+00	1.7E-02	1.5E+06	1.5E+03	3.1E+00	1.1E+06	1.1E+03	2.2E+00	1.3E+06	1.3E+03	2.5E+00	1.1E+05	1.1E+02	2.2E-01		
C ₁₆ -C ₂₁	1000	1.3E+03	1.3E+00	2.6E-03	1.0E+03	1.0E+00	2.1E-03	4.2E+04	4.2E+01	8.4E-02	1.5E+05	1.5E+02	3.0E-01	8.7E+04	8.7E+01	1.7E-01	5.4E+02	5.4E-01	1.1E-03	1.0E+03	1.0E+00	2.0E-03	3.2E+02	3.2E-01	6.3E-04	1.8E+05	1.8E+02	3.6E-01	1.7E+05	1.7E+02	3.4E-01	1.4E+05	1.4E+02	2.8E-01	8.7E+04	8.7E+01	1.7E-01		
C ₂₁ -C ₂₅	1000	1.5E-01	1.5E-04	3.1E-07	7.8E-02	7.8E-05	1.6E-07	1.1E+02	1.1E-01	2.2E-04	4.3E+02	4.3E-01	8.5E-04	4.8E+03	4.8E+00	9.6E-03	2.5E+00	4.3E-03	4.9E-06	3.0E+00	4.8E-03	3.0E-03	6.0E-06	4.7E-01	4.7E-04	9.4E-07	2.0E+02	2.0E-01	4.0E-04	1.9E+03	1.9E+00	3.9E-03	3.7E+02	3.7E-01	7.4E-04	4.7E+03	4.7E+00	9.4E-03	
C ₂₁ -C ₂₅	NA	5.5E-04	NA	NA	3.5E-04	NA	NA	1.6E-05	NA	NA	4.8E-04	NA	NA	1.9E-01	NA	NA	1.8E-04	NA	NA	2.5E-04	NA	NA	1.2E-04	NA	NA	1.2E-04	NA	NA	3.6E-02	NA	NA	1.0E-04	NA	NA	8.1E-02	NA	NA		
Sum of Aliphatics		5.0E+08	NA	NA	4.3E+08	NA	NA	2.1E+08	NA	NA	1.1E+07	NA	NA	1.8E+06	NA	NA	3.8E+08	NA	NA	2.9E+08	NA	NA	3.3E+08	NA	NA	8.7E+06	NA	NA	9.1E+06	NA	NA	8.6E+06	NA	NA	3.0E+06	NA	NA		
Total Hydrocarbon	NA	5.4E+08	NA	NA	4.8E+08	NA	NA	2.2E+08	NA	NA	1.2E+07	NA	NA	2.2E+06	NA	NA	4.3E+08	NA	NA	3.5E+08	NA	NA	3.6E+08	NA	NA	9.9E+06	NA	NA	1.1E+07	NA	NA	1.1E+07	NA	NA	3.7E+06	NA	NA		
GRO aromatics (C ₈ to C ₁₀)	NA	4.2E+07	NA	NA	4.6E+07	NA	NA	7.2E+06	NA	NA	1.7E+06	NA	NA	3.8E+05	NA	NA	5.2E+07	NA	NA	6.0E+07	NA	NA	2.4E+07	NA	NA	1.0E+06	NA	NA	1.6E+06	NA	NA	2.3E+06	NA	NA	7.1E+05	NA	NA		
GRO aliphatics (C ₈ to C ₁₀)	18400	5.0E+08	2.7E+04	5.4E+01	4.3E+08	2.3E+04	4.7E+01	2.1E+08	1.2E+04	2.3E+01	9.1E+06	4.9E+02	9.9E-01	1.6E+06	8.6E+01	1.7E-01	3.8E+08	2.1E+04	4.1E+01	2.9E+08	1.6E+04	3.1E+01	3.3E+08	1.8E+04	3.6E+01	7.0E+06	3.8E+02	7.6E-01	7.8E+06	4.3E+02	8.5E-01	7.1E+06	3.9E+02	7.8E-01	2.8E+06	1.5E+02	3.0E-01		
DRO aromatics (C ₁₀ to C ₂₁)	200	2.5E+05	1.3E+03	2.5E+00	2.9E+05	1.4E+03	2.9E+00	9.5E+04	4.8E+02	9.5E-01	2.1E+05	1.1E+03	2.1E+00	2.9E+04	1.2E+02	2.5E-01	1.0E+05	5.1E+02	1.0E+00	1.4E+05	7.0E+02	1.4E+00	2.5E+03	1.2E+01	2.5E-02	1.2E+05	6.0E+02	1.2E+00	1.5E+05	7.6E+02	1.5E+00	2.8E+05	1.4E+03	2.8E+00	2.4E+04	1.2E+02	2.4E-01		
DRO aliphatics (C ₁₀ to C ₂₁)	1000	2.5E+05	2.5E+02	5.0E-01	2.9E+05	2.9E+02	5.7E-01	2.4E+05	2.4E+02	4.8E-01	1.5E+06	1.5E+03	2.9E+00	2.2E+05	2.2E+02	4.3E-01	1.2E+05	1.2E+02	2.5E-01	2.2E+05	2.2E+02	4.3E-01	8.9E+03	8.9E+00	1.8E-02	1.7E+06	1.7E+03	3.4E+00	1.3E+06	1.3E+03	2.5E+00	1.4E+06	1.4E+03	2.8E+00	2.0E+05	2.0E+02	4.1E-01		
RRO (C ₂₁ to C ₂₅)	NA	9.2E-04	NA	NA	5.8E-04	NA	NA	4.8E-04	NA	NA	7.9E-04	NA	NA	1.9E-01	NA	NA	2.8E-04	NA	NA	3.6E-04	NA	NA	1.2E-04	NA	NA	1.2E-04	NA	NA	7.2E-02	NA	NA	6.3E-04	NA	NA	2.5E-01	NA	NA		

BTEX data not available for samples 9 through 12 at time of draft report

Table 13 PAH Vapor Concentrations in Equilibrium with the NAPL of Selected Fuels and Fraction of Risk Associated with Vapor Concentrations (from water sample data)

ANALYTE	vapor risk based concentration ug/m ³	FH JP4 W 6A		P DF W 2A		T JA W 4A		T DF2 W 3A		FH DF1 W 5A	
		P5B1042-01		P5B1042-11		P5B1042-24		P5B1042-20		P5B1042-28	
		Vapor Concentration ug/m ³	fraction of risk based level in equilibrium with oil	Vapor Concentration ug/m ³	fraction of risk based level in equilibrium with oil	Vapor Concentration ug/m ³	fraction of risk based level in equilibrium with oil	Vapor Concentration ug/m ³	fraction of risk based level in equilibrium with oil	Vapor Concentration ug/m ³	fraction of risk based level in equilibrium with oil
Acenaphthene	210	1.58E-06	7.50E-09	8.13E-06	3.87E-08	1.58E-06	7.50E-09	7.81E-06	3.72E-08	4.61E-06	2.19E-08
Anthracene	1100	6.68E-07	6.07E-10	1.34E-06	1.21E-09	6.68E-07	6.07E-10	1.34E-06	1.21E-09	6.68E-07	6.07E-10
Benzo (a) anthracene	0.11587302	3.43E-08	2.96E-07								
Benzo (a) pyrene	0.00016222	1.16E-08	7.14E-05								
Benzo (b) fluoranthene	0.11587302	1.14E-06	9.82E-06								
Benzo (k) fluoranthene	1.15873016	8.50E-09	7.34E-09								
Chrysene	11.5873016	9.70E-07	8.37E-08								
Dibenzo (a,h) anthracene	0.0115873	3.02E-10	2.60E-08								
Fluoranthene	140	1.65E-07	1.18E-09								
Fluorene	140	2.90E-06	2.07E-08	2.56E-05	1.83E-07	2.82E-06	2.01E-08	1.80E-05	1.28E-07	6.11E-06	4.36E-08
Indeno (1,2,3-cd) pyrene	0.11587302	1.64E-08	1.42E-07								
Naphthalene	3	4.16E-03	1.39E-03	2.46E-03	8.18E-04	9.15E-03	3.05E-03	6.42E-03	2.14E-03	1.09E-02	3.64E-03
Pyrene	110	1.13E-07	1.03E-09								

All vapor concentrations calculated from water test / solubility data

Only bold values represent detections, all other sample results are 1/2 detection limit

Figures

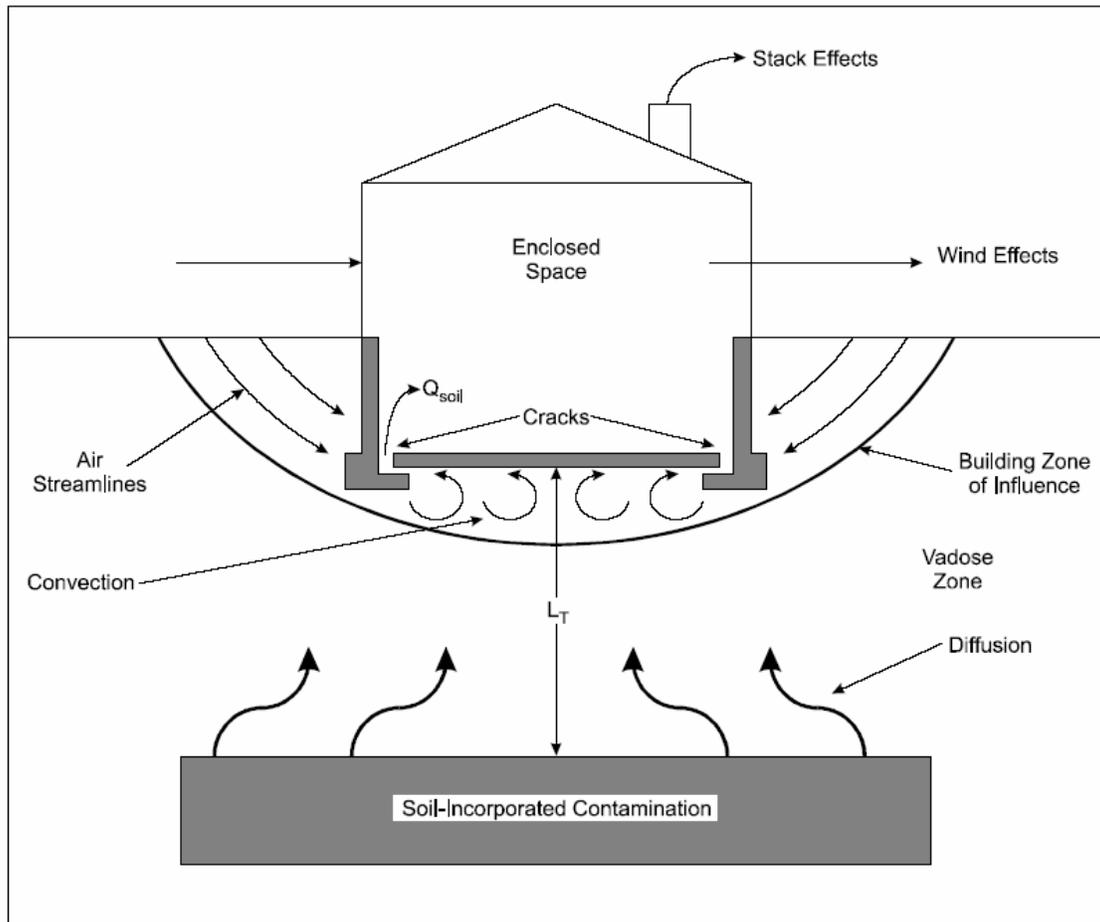


Figure 1 Conceptual Drawing of the Vapor Intrusion Route (from Environmental Quality Management, 2004).

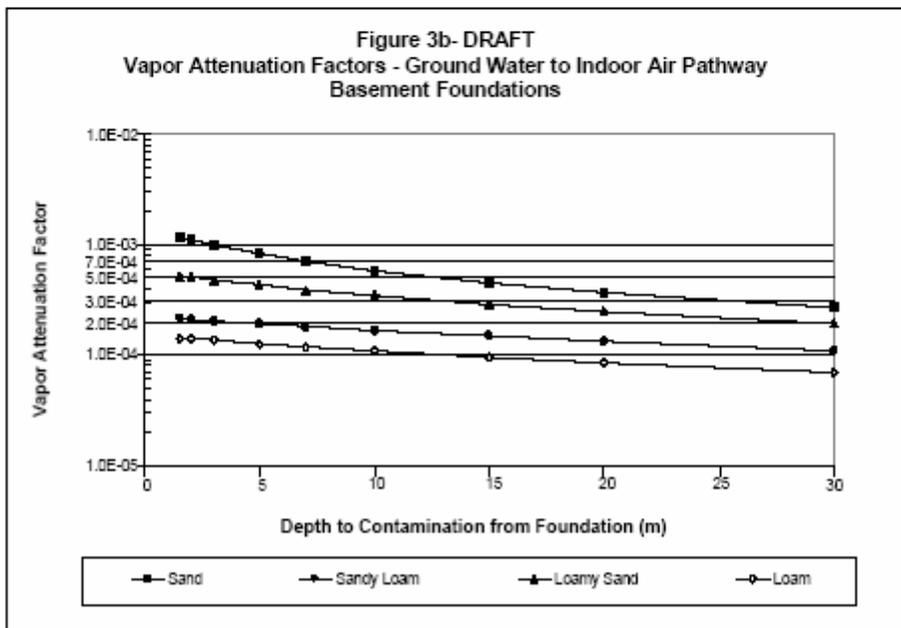
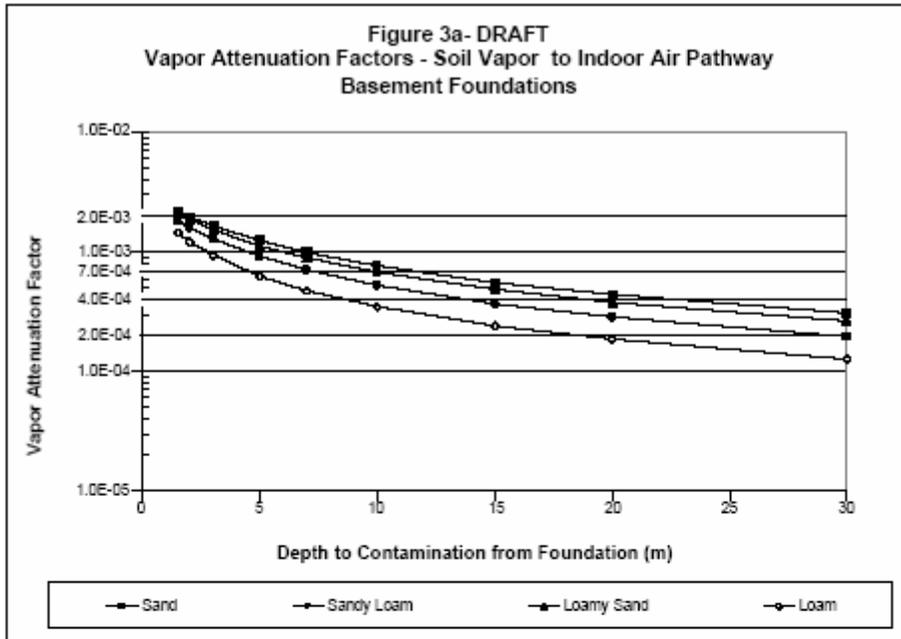


Figure 2 EPA Graphs used to Select an Attenuation Factor for Tier 2, Method 2 Screening (from EPA, 2002).

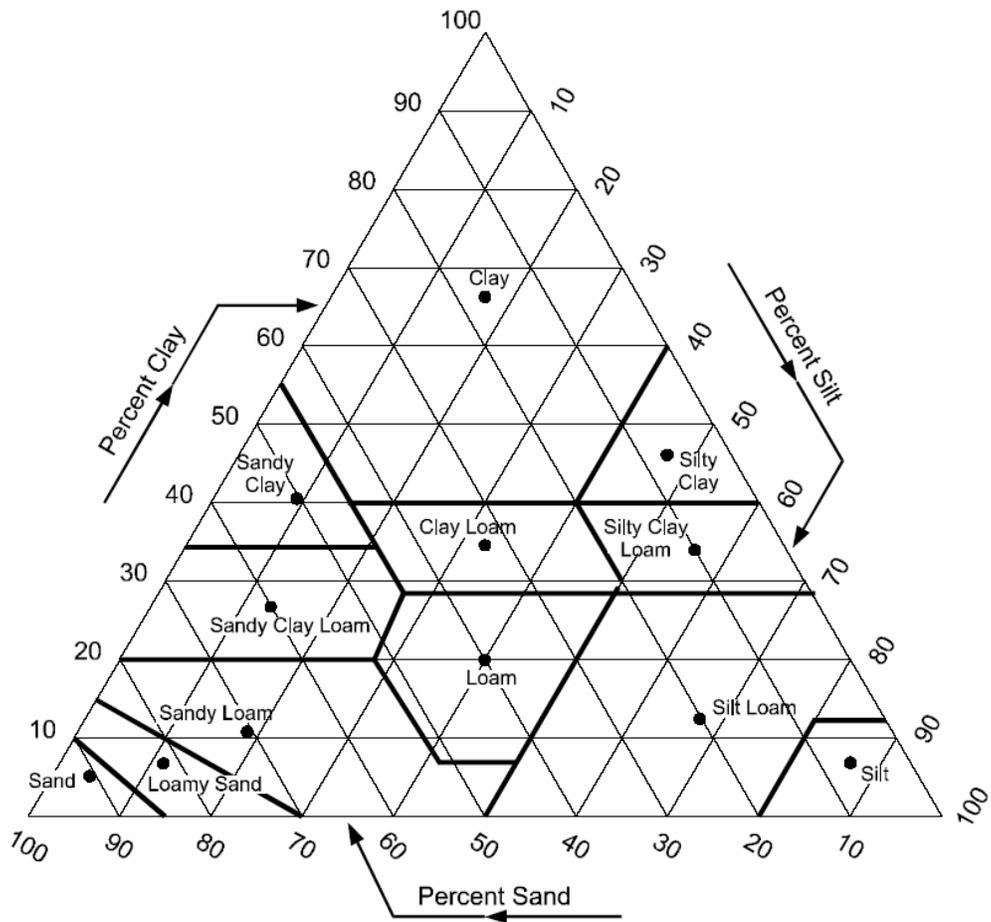


Figure 3 U.S. Soil Conservation Service Soil Texture Classification Chart Showing Centroid Compositions (from Environmental Quality Management, 2004).