Appendix A

Exposition of Major Modeling Elements of Screening Risk Assessment for Possible Radionuclides in the Amchitka Marine Environment

A.1.0 Introduction

This appendix describes 11 major elements of the model for two types of human exposure (i.e., subsistence users and commercial catch consumers) to possible radionuclides from nuclear tests on Amchitka Island. Specifically, the model focuses on 19 radionuclides associated with the Amchitka tests that might be transported by groundwater to the seafloor. The document also summarizes the current state of our knowledge about the modeling elements and the use of the available data for the risk assessment modeling.

Model elements have been advanced in a series of intermediate reports that have received DOE and stakeholder inputs. The elements are identified to the right of a schematic (Figure A.1) that shows the inputs that are required to describe the possible flow of radionuclides from the ocean floor to native Alaskan consumers of marine biota (subsistence users) and consumers of commercial catches. Those elements, progressing from release at the bottom of the schematic to human intake at the top of the schematic, are as follows:

1. Radionuclides of potential concern
2. Locations of releases
3. Seabed substrates
4. Transport by currents
5. Dilution including plume
6. Human receptors
7. Distribution of diet
8. Bioconcentration factors
9. Fraction of contaminated diet
10. Cancer morbidity risk coefficients
11. Limits to cancer risk

The following text discusses each element, starting with the ROPCs through transport and diet and ending with the limits to cancer risk. Cancer risk is initially expressed as a radionuclide risk factor, which was multiplied by the predicted radionuclide fluxes to compute cumulative risks from food eaten by the subsistence user or commercial catch consumer. Discussion of each element begins with a description, presents current knowledge, and then describes how the process is being implemented.

A.2.0 Radionuclides of Potential Concern

A.2.1 Description

Nineteen radionuclides were chosen for this study. They are radionuclides that (1) could have been present in, or produced by, the nuclear devices detonated on Amchitka; (2) have sufficiently long half-lives (>10 years) to be an ongoing concern; and (3) have published BCFs and CMRCs.

A.2.2 Current Knowledge

The initial hydrogeological modeling approach included 24 radionuclides or decay products (DRI, 1999) obtained from the Smith (1997) list of significant radionuclides and classified sources. Five nuclides were eliminated: krypton-85, which is a gas and has no CMRC; and rubidium-85, zirconium-90, barium-137, and europium-151, which are nonradioactive decay products. This resulted in 19 radionuclides. The BCF is a measure of the transfer of radionuclide from an abiotic medium (e.g., seawater) through the food chain to a receptor (e.g., fish), and the CMRC is a measure of the lifetime risk of excess cancers in humans per picocurie of radiation absorbed. The remaining 19 radionuclides are listed on Table A-1.

A.2.3 Discussion of Uncertainties

The radionuclides of potential concern were chosen from radionuclides produced by nuclear testing that are well known based upon theoretical physics and observation. An inventory of 57 radionuclides with half-lives in excess of 10 years has been compiled in classified reports for each of the experiments conducted beneath the NTS and those conducted off the NTS. Similar information is available in unclassified reports (Smith 1995; Bowen et al., 2001). The 19 radionuclides modeled for this risk assessment were selected using these sources.

Table A-1
Radionuclides Selected for Hydrogeological and Risk Assessment Modeling

Radionuclide	Present in Nuclear Devices	Produced by Nuclear Devices	Half-Life (Year)
Tritium	Yes		1.24E+01
Carbon-14		Yes	5.73E+03
Chlorine-36		Yes	3.01E+05
Strontium-90		Yes	2.91E+01
Yttrium-90[a]		Yes	7.30E-03
Technetium-99		Yes	2.13E+05
Iodine-129		Yes	1.57E+07
Cesium-137		Yes	3.00E+01
Samarium-151		Yes	9.00E+01
Europium-152		Yes	1.33E+01
Gadolinium-152		Yes	1.08E+14
Uranium-234	Yes		2.45E+05
Uranium-236	Yes		2.34E+07
Uranium-238	Yes		4.47E+09
Neptunium-237	Yes		2.14E+06
Plutonium-239	Yes		2.41E+04
Plutonium-240	Yes		6.54E+03
Plutonium-241	Yes		1.44E+01
Americium-241	Yes		4.32E+02

[a] Retained because yttrium-90 is a daughter of strontium-90.

The accuracy of a particular inventory depends in large part on the source of information for the included nuclides. Nuclides whose abundances were measured directly (from post-detonation core samples) are more accurate than those based on device characteristics and performance. Bowen et al. (2001) estimate the accuracies for nuclide groups as follows:

Fission products	~10% to 30% for most fission products
Unspent fuel material	~20% or better
Fuel activation products	~50% or better
Residual tritium	~300% or better
Activation products	~a factor of 10

It is assumed the group of 19 radionuclides are expected to contribute the most to potential risk from nuclear testing at Amchitka.

A.2.4 Implementation

The radionuclides shown in Table A-1 were used for the risk modeling.

A.3.0 Locations of Releases

A.3.1 Description

Contaminants are hypothesized to be transported to the seabed by groundwater flow. The time and location of the releases likely determine the subsequent transport by currents, dilution and plume size and shape, uptake by local biota, and other factors described by the model elements.

A.3.2 Current Knowledge

Groundwater modeling was done to predict the locations, time elapsed after the test detonations, duration, and rates of release. The use of this information for the risk assessment is discussed below. Additional information is provided in this section to illustrate the locations of the potential releases and provide a perspective on the locations of the radionuclide sources relative to the Amchitka environment (e.g., the Pacific Ocean and the Bering Sea).

A.3.2.1 Groundwater Modeling

Groundwater modeling was conducted by DRI in Las Vegas, Nevada. Preliminary results showed that tritium could be released to the seabed over a period of several decades and over distances from ~0.25 to ~4.5 km from the shoreline. Tritium is assumed to move with the speed of groundwater, while other radionuclides may be retarded by interactions with components of the subsurface medium. The degree of retardation depends on chemical properties of the radionuclides and other factors.

Island hydraulics dictate that a groundwater divide runs along the long axis of Amchitka, separating groundwater flow to the Bering Sea from that of the Pacific Ocean. The Cannikin and Long Shot sites are north of the groundwater divide, and the Milrow site is south of the groundwater divide. Therefore, it is assumed that potential releases from Long Shot and Cannikin are into the Bering Sea, whereas potential releases from Milrow are into the Pacific Ocean. The predicted locations of the releases are shown in Figure A.2. This figure shows the location of each test as a dot on a line perpendicular to the general trend of the island. The approximate groundwater divide is shown as a bar at the centerline of the island and on the transverse line through the test site.

Uncertainty in some input parameters concerning the groundwater flow system and behavior of substances during subsurface transport result in a distribution of locations where groundwater is predicted to emerge at the seabed when the model is run many times. This is because the groundwater model is a probabilistic model in which uncertain parameter values can vary each time the computation is done. The location nearest to the shore where releases are predicted to occur is termed the "first edge." Similarly, the location farthest from the shore where releases are predicted to occur is termed the "second edge." For this evaluation, the groundwater model produced a distribution of hundreds of predicted first and second edges. The nearest predicted first edge and the farthest predicted second edge are shown on Figure A.2 as bars on the transverse lines. The 75- and 300-ft isobaths around Amchitka are labeled to facilitate understanding of further discussion about depths. The perpendicular lines at each site are also locators for cross-section drawings of the sites, which will be presented in the next subsection.

Due to the uncertainty about the location of releases, the risk assessment uses the 5th percentile lower bound of the distribution of the first edge to define the shoreward edge of the zone of release. The 95th percentile upper bound of the distribution of the second edge was used to define the seaward edge of the release for all three sites. The 75-ft isobath was used to define the area in which stands of kelp and slow currents are expected to occur. The distance of the 75-ft depth from the shoreline on a line perpendicular to the island's axis was measured on a map. The locations of the first and second edges bounded in this way for each of the test sites, and of the 75-ft depth for the Milrow Site, are shown in Table A-2.

Table A-2
Extremes and Statistically-Derived Boundaries and Depth-Defined Boundaries of Modeled Release Zones for Radionuclides (Distances From the Groundwater Divide at Amchitka)

Location	Approximate Distance From The Shoreline (m)				
	First Edge		Second Edge		75-Foot Depth
	Nearest Edge	5th Percentile Lower Bound	95th Percentile Upper Bound	Farthest Edge	
Cannikin	1,470	1,470	4,520	5,320	NA
Long Shot	530	770	3,470	4,170	NA
Milrow	240	260	3,704	5,740	2,690

NA = Not applicable

A.3.2.2 Subsurface Orientation

This section presents cross-section drawings to provide a sense of the locations in two dimensions of the test cavities and the release areas, using information from a topographic map (USGS, 1975). Figure A.2 shows a view of Amchitka with transverse lines to indicate the locations of the cross-sections described in this paragraph. Figure A.3 shows the cross-sections for Cannikin, Long Shot, and Milrow. The cross-sections provide a scaled view showing the position of the borehole and the locations of the blast cavities relative to the Pacific Ocean and Bering Sea.

A.3.3 Discussion of Uncertainties

For risk assessment modeling purposes, it was assumed that the groundwater is released from a point source between the geographic limits of locations predicted by groundwater modeling, the first and second edges. In fact, it is unlikely that a plume of material subject to subsurface dispersion as it travels for 2 to 3 km through the subsurface from the detonation cavities to the first edge at the sea floor (and up to 7 km to the second edge) will remain small enough to be considered a point source. The groundwater model predicts many potential paths that resulted from variations in model parameters. For the risk assessment model, precise knowledge about the location and nature of the release is important only for ocean dispersion modeling discussed in Section A.6.0, which states that modeling a point source is more conservative than modeling a discharge that is spread out.

A.3.4 Implementation

The 5th percentile lower bound of first edges and the 95th percentile upper bound of second edges at each site were used to calculate the location of the potential releases perpendicularly from the shore. The releases were assumed to occur at a point source halfway between those locations. The zone in which kelp grows was assumed to extend to 75 ft in depth.