5.0 DOSE MODELING

The NRC's post-decommissioning dose limit is constrained by the maximum allowable annual dose from all sources (in excess of background radiation contributions) of 100 mrem/y. A number of federal agencies, including the NRC (in regulation), as well as nationally and internationally recognized bodies recommending safe levels for public exposure (ICRP 1990, NCRP 1993), specify a limit on annual public radiation dose contribution of 100 mrem/y. Since it is possible that public exposure will occur from more than one site (such as the Tobico Marsh SGA Site), only a fraction of the maximum allowable dose is typically allotted to any single site. Within the jurisdiction of the NRC, the fraction allotted to a single site is specified in regulation. The compliance limit for unrestricted release and reuse[1] of the site is 25 mrem/y (NRC 1997a).

Computer modeling codes are used to derive a concentration-based site-specific guideline that is protective of the 25 mrem/yr established dose limit. A concentration-based guideline is critical to the license termination process since potential future dose (the performance criterion for obtaining release of the site) is a projection of future exposures, which cannot be physically measured. On the other hand, a media-specific concentration derived from the expected future human exposure scenarios can be physically measured. That derived concentration is then submitted for regulator approval. The derived concentration guideline level (average concentration) is identified as the $DCGL_W$.

5.1 UNRESTRICTED RELEASE USING SITE-SPECIFIC INFORMATION

As in any health risk assessment, the process involves defining the source(s), the Site conceptual model, the pathways for potential human exposure, and the availability of a receptor to receive a dose (see Figure 5–1).

The relationships between factors involved in defining the mechanisms for human exposure are complex and often interdependent. A computer program to model the plausible human exposure scenarios and to perform complex sets of computations is employed. The model portrayed in the computer code must sufficiently represent the actual Site-specific case, in order to achieve realistic correlation between dose and concentration. As source concentrations and pathway factors affecting concentrations to receptors vary, the potential for dose also varies. Factors affecting the mechanisms for, and intensity of, human exposure must be identified, and appropriate values must be defined. Many of these factors are highly dependent upon Site-specific conditions (e.g., wind velocity), while others are more related to fundamental physical properties independent of the specific Site location (e.g., mass loading for inhalation). Many others

1 "Release for unrestricted use" is the term used by the NRC to indicate that there are no conditions or restrictions (e.g., institutional controls prohibiting residential uses of the property in the future) that must be emplaced by the licensee to ensure that the future uses of the site are consistent with the uses that are determined to be safe for public exposure to residual radioactivity originating from the site.

are dependent upon the availability and projected activities of receptors (e.g., hours per day at the Site). To accurately determine the values to be used for many of these factors that become input parameters to the computer modeling codes, the risk assessor must first envision and characterize the plausible future exposure scenarios that a potential receptor may encounter. Clearly defining the expected future human exposure scenarios is key to obtaining a realistic correlation between projected future dose and existing source concentrations.

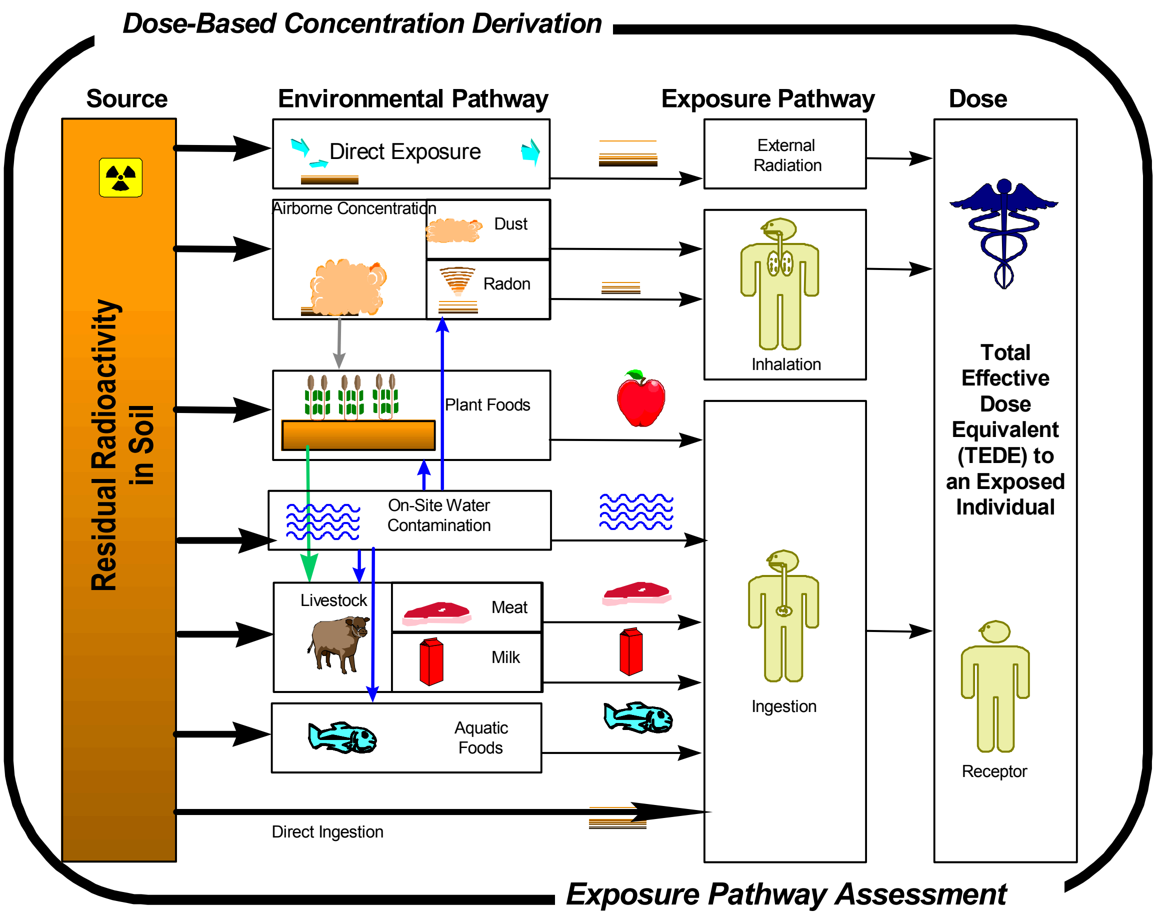

Figure 5–1 Conceptual Human Exposure Assessment Model

After human exposure scenarios are conceived, the second key element to be considered in constructing representative exposure models is determining which pathways are potentially complete from source to receptor. The conceptual pathway model shown in Figure 5–1 includes all conceivable pathways for human exposure to residual radioactivity associated with the Site. Not all of those pathways are potentially complete for a variety of reasons. Tables explaining which of the specific pathways are complete for each scenario evaluated are contained in the subsequent sections detailing each scenario.

Fundamentally, there are two types of risk assessment methods: deterministic and probabilistic. Most professionals are familiar with the deterministic approach because it has been, until recently, the most widely used of the two. The deterministic health risk assessment method is designed to capture the reasonable maximum exposure (RME) condition for a receptor using single point estimates of parameter values used to calculate dose. Such a calculation provides the risk manager with a single point estimate of dose that could result from a given concentration of radioactivity. Few parameters used to calculate future dose potential are so well known that they can be described by a single value. In recognition of this limitation, deterministic risk assessments typically use overly conservative values for parameters in an attempt to bound the inherent uncertainty.

By contrast, the probabilistic methodology specified by the NUREG-1727 (NRC 2000) addresses extreme-case exposure potential through what is essentially an uncertainty analysis, taking the range and distribution of individual parameters into consideration. The probabilistic method provides a substantially clearer picture of the potential future dose corresponding to a residual radioactivity concentration for the risk manager to evaluate.

Rather than using the RME for the entire population (as is the case in the typical deterministic method risk decisions) the probabilistic method allows the risk manager to focus on what is termed the "critical exposure group." The critical exposure group is the sub-population expected to be the most exposed among those who may receive exposures at the site. The NRC establishes the decision criterion based upon the use of a probabilistic assessment method and the resulting mean or "most likely" exposure to an exposed member of the critical exposure group (NRC 1997a, NRC 2000). Table 5-1 summarizes the principal differences that exist between the deterministic and probabilistic methods.

Table 5-1 Comparison of Methodologies

	Probabilistic	**Deterministic**
Measure of Human Health Detriment	Annual Radiation Dose measured in millirems per year	Annual Radiation Dose measured in millirems per year
Parameter Value Basis	Mean value for average member of a defined critical exposure group in a specific exposure scenario	Reasonable Maximum Value picked from accepted default values
Calculation Method	Computer Modeling Code	Algebraic summation using Spreadsheet (or older computer codes without Monte Carlo sampling algorithms).
Time Integration	Yes. Integration intervals vary to allow for radioactivity in growth, decay and transport.	No. Point estimate, considering discrete point in time and Site conditions

MDNR has selected the computer-based, dose-modeling code RESRAD Version 6.21 (the latest non-beta version as of the writing of this decommissioning plan) to perform the site-specific dose modeling in support of the decommissioning of the Tobico Marsh SGA site (Yu 2002). RESRAD is chosen primarily because it adequately depicts the key site-specific features of the MDNR site that impact the potential future dose to a receptor exposed at the site. Among the other advantages that RESRAD brings to a radiological dose or risk assessment is its ability to derive values for exposure parameters based on built-in fate and transport computations using well-defined site-specific data. It is also able to integrate dose and risk projections over time taking into account transient conditions over that period. It is widely accepted as an industry standard tool for performing radiological dose assessments and specifically for deriving concentration guideline values. For the derivation of the Site-specific DCGL, a probabilistic analysis will be presented using the range and distribution of values for parameters expected for the site-specific exposure scenarios and conditions considered.

A few of the key points that should be recognized about the RESRAD modeling code and the algorithms it uses are:

- Default Dose Conversion Factors (DCFs) used in RESRAD 6.21 are taken from FGR #11 (EPA 1988a), FGR #12 (EPA 1993), and are derived using the ICRP 30 dosimetry model. The bio-kinetic dosimetry model accounts for particle fractioning that might occur following exposure. For example, the DCFs for particle inhalation account for the dose to the GI tract from the fraction of respired particles that are ingested. As a result, there is no need to independently account for biological fractioning in the dose calculations.
- Short-lived (<180 days) radioactive progeny isotopes are accounted for using the "parent+D" DCFs.
- RESRAD integrates and normalizes exposure factors based on the fraction of time a receptor is exposed over the exposure period. For example, a soil ingestion rate of 100 mg/d for a receptor who is exposed on Site for only 50-percent of one day would result in an ingestion intake of 50 mg.
- RESRAD requires that the risk assessor input single-point estimates for values of every parameter required to evaluate complete pathways in the deterministic module of the code. RESRAD uses the single-point deterministic value for a specific parameter to calculate dose or risk, unless the risk assessor specifies that the value be evaluated with a range of possible values selected from a specified distribution. It is not necessary to evaluate the uncertainty in every parameter, because variability (perhaps stemming from uncertainty) in many parameters does not contribute significantly to variability or uncertainty in the resulting dose.

5.2 SITE CONCEPTUAL MODEL

The site conceptual model has three fundamental components that must be conceptualized and described in terms that can be used to calculate or model the potential future dose to a receptor that might be exposed at the site. The first component is the source term itself. The size, thickness, and radiological composition of the source are conceptualized in the source term abstraction. The second component of the site conceptual model is the physical characteristics of the site itself. The site is described in the physical abstraction that includes physical and hydraulic characteristics of the site and its potentially impacted environs. The third component that must be conceptualized is the range of plausible human exposure scenarios, which are described primarily by factors that are associated with human behavior and metabolic physics. Each of these three fundamental components is discussed in the sections that follow.

5.2.1 Source Term Abstraction

The source term abstraction used by the computer modeling code to project potential future dose is derived from knowledge about the source material itself, and previously completed radiological assessments of the residual radioactivity at the site. The source term is defined by its radionuclide composition, as well as its lateral and vertical deposition (spatial configuration).

Conceptually, there are two discrete source terms for the Tobico Marsh SGA site. The primary source term involves the slag deposits that are encapsulated within the clay slurry walls and cover—the subsurface soil source term. In acknowledgement of the potential that radioactivity could have been brought to the surface (of the cover) during previous characterization sampling operations, a secondary source term—the surface soil source term—is also being evaluated. A relatively simple, two-sample, statistical test has been devised to determine whether a statistically distinguishable (measurable) amount of radioactivity is present in the area immediately surrounding the former corehole locations (see Section 14 of the DP for further details). However, the mere presence of a statistically distinguishable concentration of residual radioactivity in the surface soil around a corehole does not lead to the conclusion that a receptor might be exposed to unacceptable radiation levels. In order to address that question, a surface soil DCGL is needed in addition to a subsurface soil DCGL.

The dose modeling tools currently available do not support the simultaneous assessment of multiple source terms in soil. Consequently, it is necessary to evaluate the dose potential associated with the primary and secondary source terms independently. If *a posteriori* dose modeling were being performed, it would be a relatively simple matter to sum the resulting dose from each source term to determine compliance with the decommissioning standard. However, the DCGL development process involves *a priori* dose modeling to arrive at a source term concentration that will be protective of the decommissioning standard.

The simplest and most conservative way to approach the problem of DCGL development for multiple source terms in *a priori* dose assessment is to apportion or fraction the permissible dose limit among the source terms being evaluated. Conceptually, the allocation process is an optimization technique in which fractions allotted to each source term are considered in light of the probability that the residual radioactivity concentration in each source term will be less than the DCGL. Figure 5–2 graphically portrays the allocation concept showing the inverse relationship between allowable dose for the surface and subsurface soil source terms. Any combination of DCGLs for the two source terms that results in a total effective dose equivalent of 25 mrem annually is compliant with the decommissioning standard for unrestricted release. The combination of 5 mrem/y from the subsurface soil and 20 mrem/y from surface soil is presented as an example only. As will be shown, the projected annual dose from the subsurface soil source term to a receptor exposed at the site is significantly less than 1 mrem, leaving the majority of the 25 mrem/y decommissioning standard available for the surface soil source term.

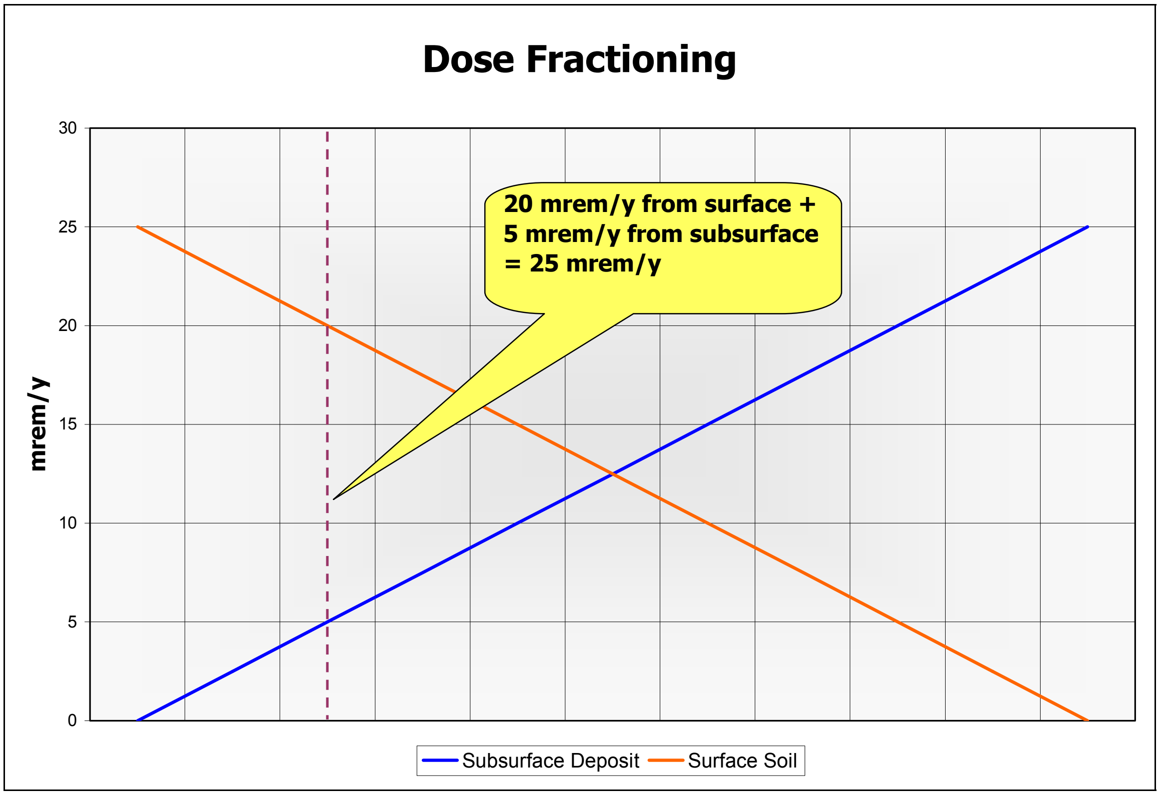

Figure 5–2 Dose Allocation Concept for Multiple Source Terms

5.2.1.1 Subsurface Soil (Primary) Source Term

The primary source term is comprised of pockets of vitreous, thorium-bearing slag deposited primarily along a track approximately 50 feet wide (15 meters) corresponding to the former access road that transected the site (approximately north to south). There is some areal variability in the measured deposition, likely owing to the haul and dump deposition mechanism that is thought to have been used to place the slag at the site.[2] Still there is an obvious correlation between the trace line describing the position of the former access road and the lateral positioning of subsurface soils with elevated radioactivity.

Based upon characterization survey results, the areal extent of elevated radioactivity within the slurry walls is approximately 800 m^2. In describing the source term for input

2 Aerial photographic evidence also suggests that slag was dumped in piles along the side of the former haul road that trended north and south through the site.

to RESRAD, the area (size) of the contaminated zone parameter (AREA) is represented by a loguniform distribution with a minimum value of 791 m^2 and a maximum value of 5,725 m^2 corresponding to the entire area within the slurry walls of the cell. The use of the loguniform distribution provides a realistic, yet conservative, description of the lateral variability in the size of the source term in that it assigns the most likely size (791 m^2) as the minimum size and allows for the possibility (albeit with lower probability of occurrence) of larger sizes up to the entire area covered by the cell.

Vertically, the radiologically significant material is located just beneath the cover (approximately 5 feet bgs) and lies in a lens that is nominally about 4 feet (1.2 meters) thick. There is, of course, some variability in the depth profile of the deposited radioactive slag material. The variability is likely the result of placing loads (piles) of slag materials in depressions along the roadside. Whatever the explanation for the variability, the radiological characterization survey suitably mapped the vertical (depth) profile and its variability. The two-dimensional depth profile is mapped for three transects within the cell where the radioactivity was most concentrated and presented in Figures 4–9 through 4–12. The north-south transect (cross section C–C', repeated in Figure 5–3 for convenience) provides the best indication of depth profile and variability as it cross sections the site along the trace of the former access road and through the most concentrated deposits of elevated radioactivity measurements on the entire site.

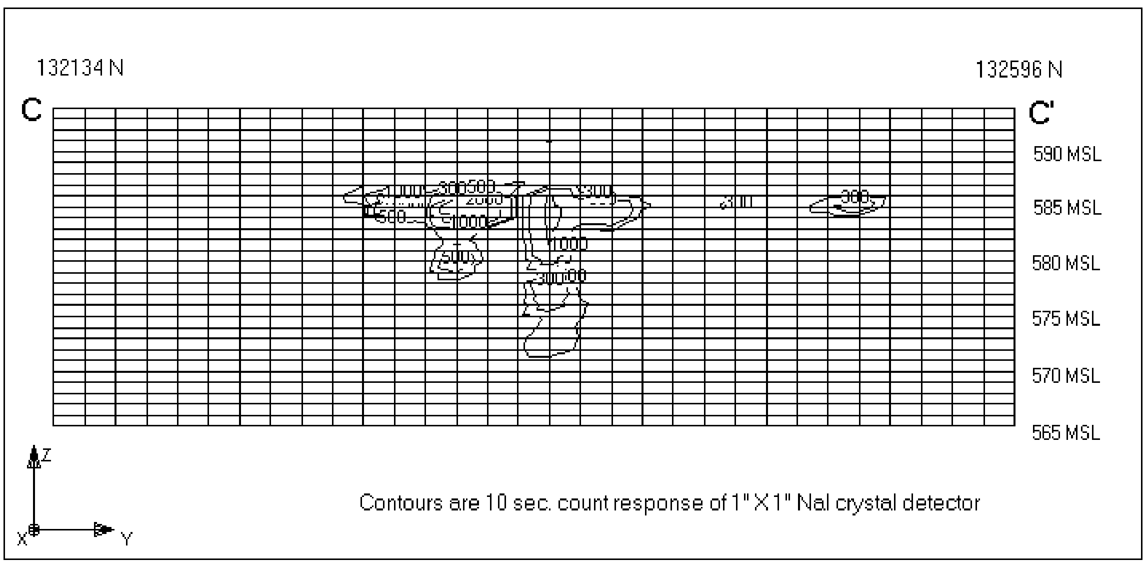

Figure 5–3 Cross Section C-C'

From Figure 5–3, it can be seen that the majority of the radioactivity lies in a lens that is approximately 5 to 6 feet below the ground surface (the thickness of the clay cover near the center of the cell) and approximately 4 feet thick. The amount of source material deposited rapidly depletes as the depth increases and terminates at a maximum thickness of approximately 15 feet in one location.

A lognormal-N distribution describes well the observed variability in the depth profile and thus the thickness of the contaminated zone or source term. In describing the source term for input to RESRAD, the thickness of the contaminated zone parameter (THICK0) is represented by a bounded lognormal-N distribution, with the central tendency (CT) value conservatively set to a thickness of 4 feet (1.22 meters). This thickness is conservative in that the mean source thickness over the entire footprint of the cell, the impacted area, is considerably less than 4 feet. It is only within the region along the former access road (the most heavily contaminated area) that the thickness averages approximately 4 feet. The distribution is bounded at a minimum value of 0 feet (0 meters), and a maximum value of 15 feet (4.5 meters).

As described in Section 4.4.3, radionuclide composition of the source term (*the nuclides of interest*) is defined by both measured isotopic ratios in soils samples collected from within the contaminated volume of the cell and by historical knowledge of the origin of the radioactivity found within the slag. The volume-weighted activity ratio between the isotopes of Th-230 and Th-232 is calculated to be 3.1:1. Measured activity ratios in individual samples ranged from 0.5:1 to as high as 11:1 (Cabrera 2001). In describing the source term for input to RESRAD, it is logical that the volume-weighted ratio would be used as ratios greater than 1:1 (the most common and prevalent relationship between the two isotopes) were found in only two discrete locations within the cell.

The relatively longer-lived progeny of Th-232 are assumed to be in secular equilibrium with Th-232. This assumption is conservative but frequently supported by analytical measurements. The relationship between Th-230 and its longer-lived progeny was calculated by decaying Th-230 for 50 years (the estimate of time elapsed since the thoriated slag was potentially produced) and determining the ingrowth of Ra-226 and its progeny, Pb-210. The calculated ratios between Th-230 and Ra-226 agree with the ratios typically measured in samples collected from within the contaminated soil volume. The source term input to RESRAD includes all of the isotopes in the Th-230 and Th-232 decay series with half-lives longer than 180 days and in the following ratios[3].

- Pb-210 0.5%
- Ra-226 1.1%
- Ra-228 16.1%
- Th-228 16.1%
- Th-230 50.0%
- Th-232 16.1%

5.2.1.2 Surface-Soil (Secondary) Source Term

The surface-soil source term is secondary in that it is considered unlikely to contain a significant amount of residual radioactivity. In fact, the surface-soil source term is a

3 Isotopes with half-lives shorter than 180 days are assumed to be in equilibrium with their first parent with a half-life greater than 180 days and are accounted for in dose calculations through the use of “parent+D” dose conversion factors (DCF).

hypothetical source term arising from the possibility that subsurface radioactivity may have been brought to the surface and inadvertently deposited on the otherwise radiologically clean cover overlying the waste layer during the site characterization survey. It is known that precautions were emplaced during the coring, sampling, and *in situ* measurement processes associated with the characterization survey. It is also known that radiological surveys were performed during these processes to ascertain whether radioactivity was being effectively contained and controlled. Nonetheless, radiological surveys performed during characterization cannot be used to quantitatively assess the potential dose to a receptor exposed to relatively small amounts of radioactive residue lying on the surface near the corehole penetrations.

In describing the surface-soil source term for input to RESRAD, it is logical to conclude that the radiological characteristics of any residual radioactive materials would be consistent with those attributed to the subsurface-soil source term from which it is derived. Thus, the isotopic ratios and decay series equilibrium assumptions described for the subsurface-soil source term are implied for the surface-soil source term.

The areal distribution of the surface-soil source term is related to the areal distribution of the subsurface deposits as well. However, the probability that residual radioactivity is as widely distributed in surface soils as it is in subsurface soils is exceedingly small. The very nature of deposition mechanism hypothesized supports the idea that if a measurable amount of radioactivity were brought to the surface, it would be confined to a relatively localized area near the corehole placement (Figure 5–4). In addition, it is reasonable to conclude that residual radioactivity deposition in surface soils might possibly occur only around a fraction of the coreholes in which measurable subsurface radioactivity was detected.

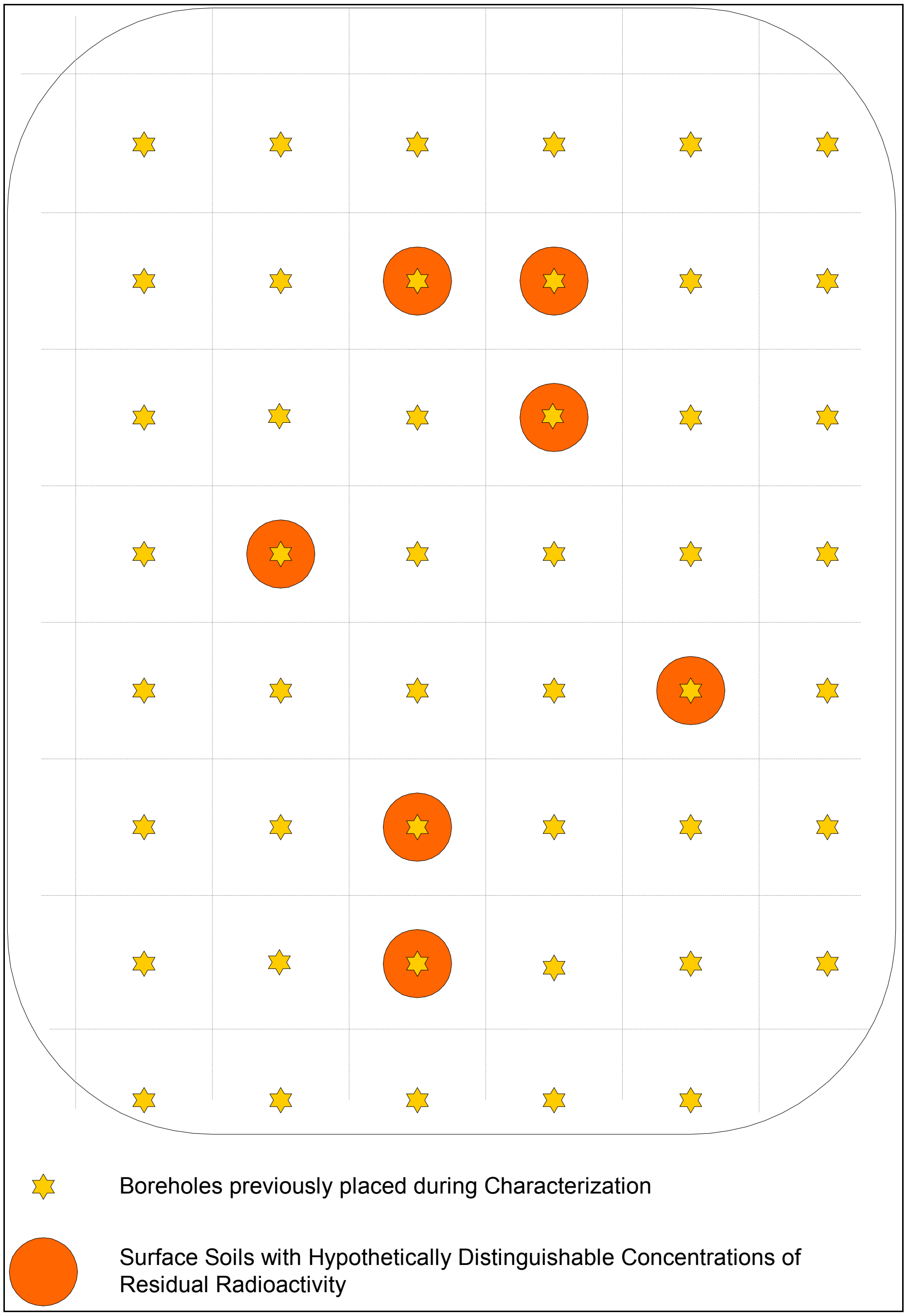

Figure 5–4 Hypothetical Surface-Soil Source Term Areal Distribution

The subsurface-soil characterization survey shows that only approximately 14-percent of the area within the confines of the slurry walls has deposits of elevated radioactivity. Assuming that, at most, 14-percent of the approximately 400 coreholes placed have the potential to have elevated concentrations of residual radioactivity, and the potentially impacted area surrounding a corehole is estimated to be 1 m^2, the maximum area for the surface soil source term is approximately 57 m^2. Given that radiological controls were in place during prior coring operations, and that elevated radiation levels have not been detected during the performance of routine monthly radiation surveys since the characterization event, it is likely that the potentially impacted area would be even smaller. For dose modeling purposes, the area (size) of the contaminated zone parameter (AREA) is represented with a triangular distribution having a minimum value of 0 m^2, a mode of 57.3 m^2 and a maximum value of 5,725 m^2 corresponding to the entire area within the slurry walls of the cell. The use of the triangular distribution provides a realistic, yet conservative, description of the lateral variability in the size of the source term. It allows for the possibility that: 1) the surface soil is not impacted, 2) assigns the most likely size (57.3 m^2) at a value that requires that a significant failure of the radiological controls occurred during characterization, and 3) allows for the possibility (albeit with lower probability of occurrence) of larger sizes up to the entire area covered by the cell.

Vertically, the potentially impacted surface-soil lies directly on the surface of the clay cover. Localized variability in the depth of surface soils potentially impacted with residual radioactivity is expected. Again, because the coring process was controlled to preclude the indiscriminant distribution of radioactivity, it is unlikely that significant volumes of soils containing radioactive slag were left on the ground surface. To arrive at a reasonable set of parameters describing the potential depth of the surface-soil source term, some bounding calculations are necessary.

The cores removed from the subsurface soil were 1.5 inches in diameter (Cabrera 2001). From Figure 5–3, it can be seen that the typical thickness of the subsurface layer containing radioactivity is approximately 4 feet (1.22 meters). The amount of subsurface source material rapidly depletes as the depth increases and terminates at a maximum thickness of approximately 15 feet (4.5 meters) in one location. The total volume of soil in a single core advanced to a depth of 5 meters is 0.0057 m^3. Considering that approximately 400 coreholes were advanced at the site, the total volume of soil extracted in cores is conservatively estimated to be approximately 2.25 m^3. Under the conservative supposition that one half of the soil core material (1.125 m^3) escaped control or was deposited on the surface in the vicinity of the corehole and taking into account the areal distribution described above, a surface soil thickness profile can be constructed. If 1.125 m^3 of soil were distributed over an area of 57.3 m^2 (the most likely area, as described above), the thickness of the potentially impacted layer would be 0.02 m (≈1 inch). If the same volume were spread over the entire area of the cover, the thickness would be less than 1 mm.

Given that these calculations are based on extreme suppositions, any description of the surface-soil source term thickness that defines the thickness with a high probability of occurring between 0.001 and 0.02 meters will be conservative. In the interest of simplicity, MDNR has chosen to represent the surface soil source term with a triangular distribution having a minimum thickness of 0 m, a mode of 0.001 m, and a maximum value of 0.02 m. The use of this triangular distribution provides a substantially conservative description of the variability in the thickness of the source term. It allows for the possibility that: 1) the surface soil is not impacted, 2) assigns the most likely thickness (0.001 m) at a value that requires that a significant failure of the radiological controls occurred during characterization, and 3) allows for the possibility (albeit with lower probability of occurrence) of a thickness up to approximately 1 inch. Because the available volume of material to be spread on the surface is fixed, the thickness and areal distribution of the surface-soil source term are co-dependent. Consequently, the distributions describing the thickness and area of the surface-soil source term have been inversely correlated with one another in the model.

5.2.2 Site Physical Abstraction

The second major conceptual component of the dose assessment is the physical abstraction of the site (see Figure 5–5). The physical abstraction captures and expresses the important physical, hydraulic, and geological conditions at the site and places the source term in the context of the environment and systems that surround it.[4] Figure 5–5 is a highly stylized and simplified depiction of the site in cross section and is used to graphically communicate the basic geophysical composition of the site.

Conceptually, the site is composed of six "layers" important to the dose modeling objective. The six layers are:

1. Surface Contaminated Zone—a very thin, hypothetically conceived, surface veneer overlying the engineered clay cover and comprised of materials brought to the surface during prior subsurface soil characterization activities and inadvertently deposited on the cover near the corehole locations.
2. Engineered Clay Cover Layer—a thick layer of unimpacted, native, clay-bearing soils brought into the site to form a cap over the subsurface contaminated zone and underlying waste layer.
3. Subsurface Contaminated Zone—a layer generally lying just beneath the clay cover in which thorium-bearing slag exists from past disposal activities at the site.
4. Underlying Waste Layer—a layer used generally to describe the physical and hydraulic aspects of the materials lying below the subsurface "contaminated zone" and above the undisturbed glacial till layer underlying the whole site.
5. Glacial Till Layer—a relatively thick, dense, undisturbed native deposit of glacial till having a high clay content. This layer forms the natural "bottom" of the engineered cell and the slurry walls of the cell are keyed into this layer.
6. Deep Aquifer Saturated Zone—a saturated zone underlying the glacial till layer from which water for domestic uses might be drawn (although it is not anticipated that water will be drawn from this aquifer on site).

4 The physical, hydraulic, and geologic conditions "important" in the context of dose modeling and derivation of the DCGL are those that must be described for input to the dose modeling code, RESRAD. RESRAD is not a comprehensive groundwater and surface water fate and transport code. It does, however, model the vertical migration of radiological contaminants from surface or near surface soils to groundwater sources of drinking water and surface water bodies for the purpose of calculating the dose potential to human receptors who might use such water. As such, detailed hydrogeologic depictions of the Site are not necessary for RESRAD to model the pertinent radiological parameters.

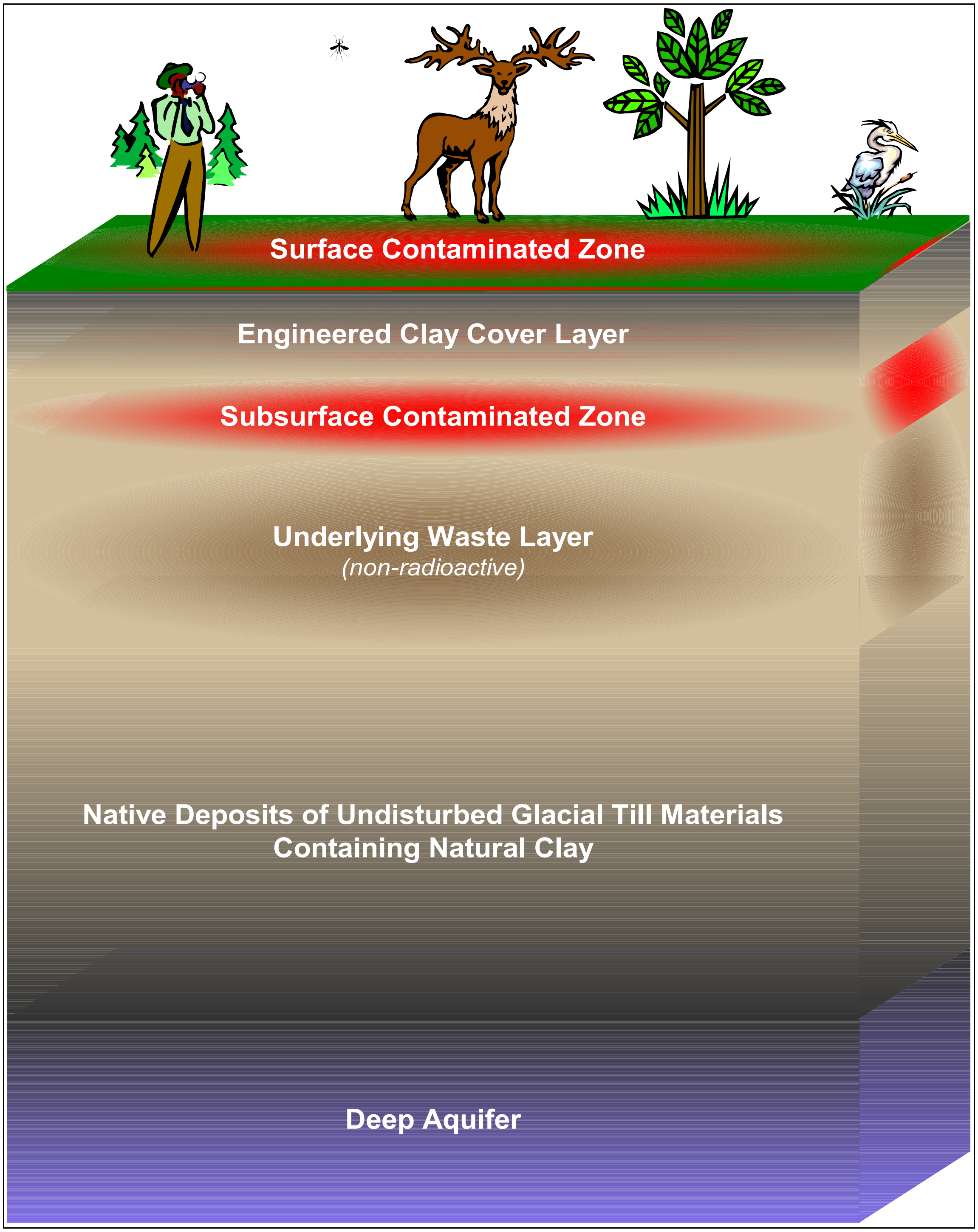

Figure 5–5 Tobico Marsh SGA Site Physical Abstraction

The RESRAD modeling code used to predict the fate and transport of radiological contaminants associated with source terms in soil cannot consider more than one source term simultaneously. Because there are two source terms being considered, it is necessary to further interpret the site physical abstraction presented in Figure 5–5 and to describe the layers and zones in two sets of terms that are used to calculate or model potential future dose to an exposed individual engaged in non-intrusive activities at the site. Figure 5–6 illustrates the interpreted site physical abstraction used in RESRAD for each of the surface soil and subsurface soil source terms. The parenthetical labels on each layer in the figure correspond to the name of the layer as depicted in the RESRAD code.

The various parameters describing the composition in each “layer” are defined within RESRAD with probabilistic variables to account for the variability and uncertainty inherent in hydrogeological features. The parameters defining each layer are described in detail in the sections that follow.

5.2.2.1 Surface-Soil Contaminated Zone

The radiological composition, thickness, and areal distribution of residual radioactivity in the surface-soil contaminated zone have previously been described in the source term abstraction, above. However, some additional features of the surface soil contaminated zone are described here. The hypothesized deposition mechanism leading to the formation of this layer is the inadvertent cross contamination of the surface of the engineered clay cover layer during the characterization survey coring operations. Thus, the composition of the surface soil layer, in terms of its density and hydraulic properties, is logically consistent with that found in the subsurface soil contaminated zone. It is described in RESRAD with a density of 1.65 g/cm^3 and a hydraulic conductivity of 2,018 m/y. It is a vitreous-like material that is, by its very nature, very insoluble. As described previously (Section 3.7.3), the effective Kd for thorium in the contaminated zone is described using the RESRAD default, lognormal-N distribution function, except that bounds have been established on the range of values sampled during probabilistic analysis (a bounded lognormal-N distribution). The central tendency value for the distribution has been set to match the default, single-point estimate used in the RESRAD deterministic module, 60,000 cm^3/g (ANL 1993, USNRC 1980). Probabilistic sampling is bounded between 3,200 and 89,000 cm^3/g, the lowest and highest geometric mean values for various soils as reported in literature and summarized in the Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil (Yu 1993). Treatment of the contaminated zone Kd value for thorium in this manner is only slightly less conservative than the default treatment of this parameter in RESRAD’s probabilistic module and is at least a conservative as the default treatment in RESRAD’s deterministic module. RESRAD default distribution coefficients were used for all other radionuclides in the source term.

When modeling the surface-soil source term in RESRAD, this layer is identified as the “contaminated zone.” It is omitted when modeling the subsurface-soil source term.

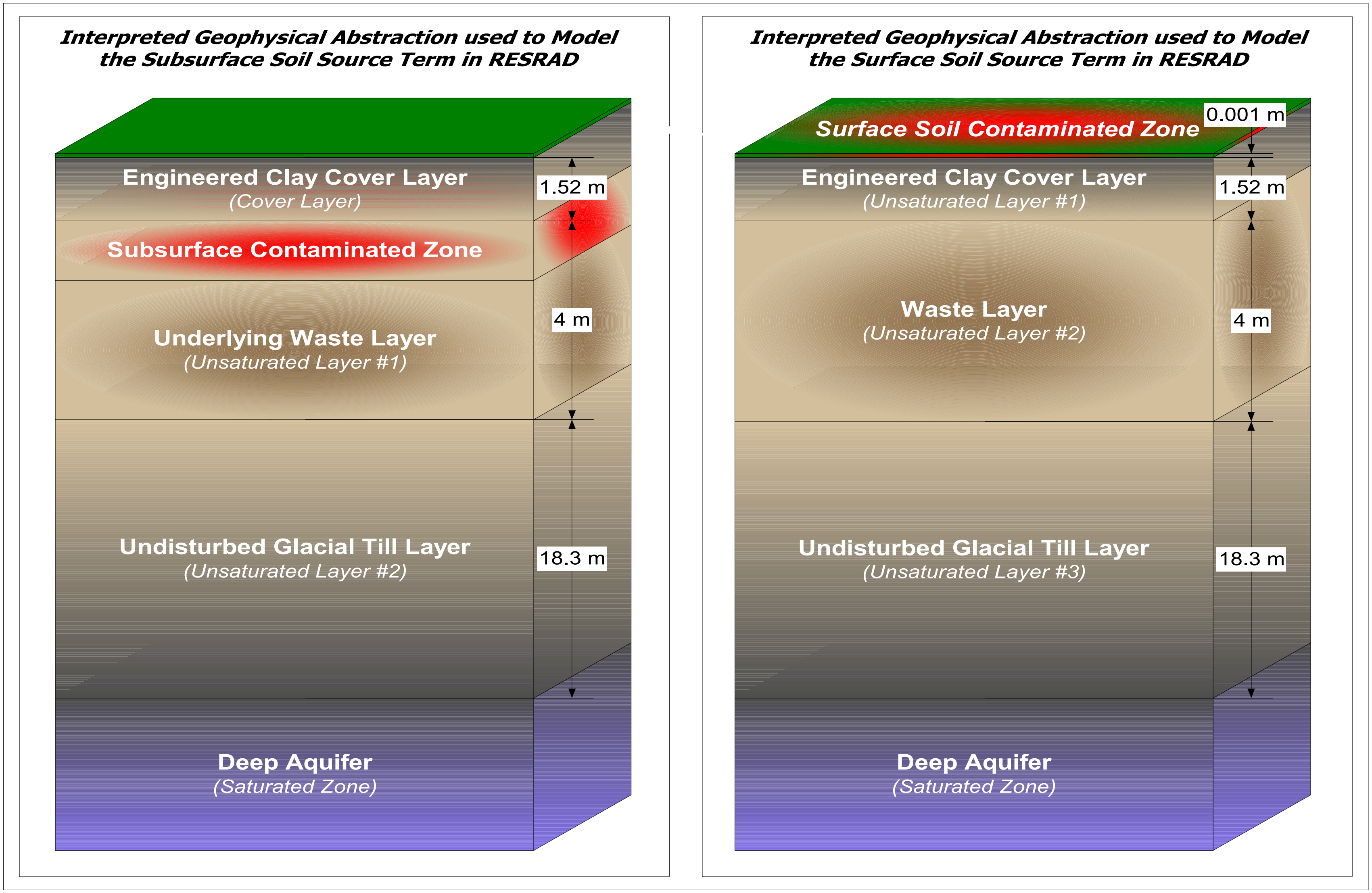

Figure 5–6 Interpreted Geophysical Abstraction as Used in RESRAD Modeling Code

5.2.2.2 Engineered Clay Cover Layer

The cover layer, which underlies the surface soil contamination zone and overlies the subsurface soil contamination zone, is an engineered soil cap made of native clay-bearing materials brought into the site and installed in 1984. It is designed to encapsulate the industrial wastes disposed at the site. The thickness of the engineered clay cover layer is reported to be 1 to 2 meters thick (~4 to 7 feet). Radiological characterization surveys confirm the clay cover thickness to be in the range of 4 to 6 feet with the cover being thicker over the central portion of the cell where the deposits having elevated concentrations of residual radioactivity are concentrated. A triangular distribution with a central tendency value of 1.52 meters and a minimum and maximum of 1 and 2 meters, respectively, is used to represent the thickness of this layer in RESRAD model.

The engineered clay soil cover is designed to have a high soil density and a low hydraulic conductivity. Soil density is assumed to be equivalent to the native clays in the region (1.97 g/cm^3) and hydraulic conductivity is assumed to be comparable to that measured in native clays (0.017 meters/y).

When modeling the subsurface-soil source term in RESRAD, this layer is identified as the “cover layer” since it overlies the subsurface-soil contamination zone. Because it underlies the surface-soil source term, it is identified as “unsaturated layer #1” in RESRAD when modeling the surface soil source term.

Cover degradation is accounted for in RESRAD by a surface soil erosion rate parameter (VCV). When modeling the subsurface-soil source term, cover erosion is defined using the RESRAD default distribution, continuous logarithmic, with the cumulative distribution spanning nearly two decades of erosion rate values and centered on the most probable erosion rate of 3.0×10^{-6} m/y.[5] The probability-density function for the cover erosion rate parameter used in RESRAD dose modeling is presented in Figure 5–7. Soil erosion is not important for this layer when modeling the surface-soil source term.

Soil samples of the cover material were analyzed to determine the potential for this layer to support gardening or crop production. Analysis of the soil samples identified high (8.4) pH levels and low potash, phosphate, and organic matter levels compared with baseline averages for Bay County. Nitrogen levels were also identified in the low to average range. Soil composition is composed of 32.8 to 34.4 percent sand, 29.8 to 30.2 percent silt, and 35.4 to 37.4 percent clay. This composition is classified as a clay loam soil type.

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5 According to the *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil* (Yu 1993), soil erosion rates for sites in humid areas, with a 2% slope, and natural succession vegetation are estimated to range between 8×10^{-7} and 3×10^{-6} m/y (based on model site calculations using the Universal Soil Loss Equation method). MDNR has allowed the soil erosion rate to range to a maximum value of 6×10^{-5} m/y, the highest cited value recommended for use in RESRAD (Yu 1993) for a site with 2% slope and for which it can be reasonably shown that the site is, and will continue to be, unsuitable for agricultural use.

Based on the soil sample results (Appendix J) and discussions with the Michigan State University Extension Center – Bay City, the cost and effort to make this soil suitable for crop production would be cost prohibitive in comparison with other available land/soil conditions.

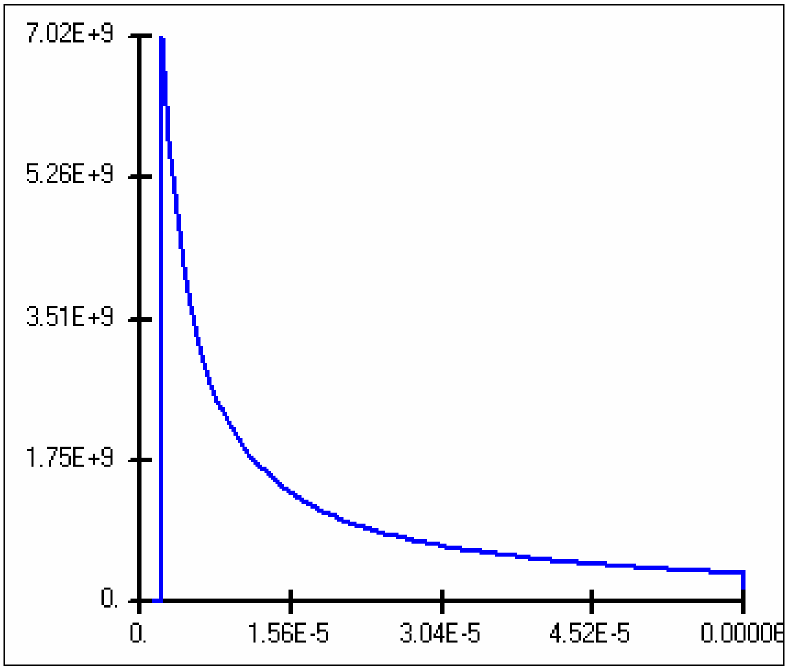

Figure 5–7 Cover Soil Erosion Rate (VCV)

5.2.2.3 Subsurface-Soil Contaminated Zone

The subsurface-soil contaminated zone has also previously been described in the source term abstraction. However, some additional features of this layer (those unrelated to its radiological composition) are described here. The thorium-bearing slag material is assumed to be comparable to the sand cover material in terms of its density and hydraulic properties. Thus it is described in RESRAD with a density of 1.65 g/cm^3 and a hydraulic conductivity of 2,018 m/y. It is a vitreous-like material that is, by its nature, very insoluble. As described previously (Section 3.7.3), the effective Kd for thorium in the subsurface soil contaminated zone is described using the RESRAD default, lognormal-N distribution function, except that bounds have been established on the range of values sampled during probabilistic analysis (a bounded lognormal-N distribution). The central tendency value for the distribution has been set to match the default, single-point estimate used in the RESRAD deterministic module, 60,000 cm^3/g (ANL 1993, USNRC 1980). Probabilistic sampling is bounded between 3,200 and 89,000 cm^3/g, the lowest and highest geometric mean values for various soils as reported in literature and summarized in the Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil (Yu 1993). Treatment of the subsurface soil contaminated zone Kd value for thorium in this manner is only slightly less conservative than the default treatment of this parameter in RESRAD's probabilistic module and is at least a conservative as the default treatment in RESRAD's deterministic module. RESRAD default distribution coefficients were used for all other radionuclides in the source term.

When modeling the subsurface-soil source term in RESRAD, this layer is identified as the "contaminated zone." In RESRAD, an unbiased simplification has been made in describing this layer when modeling the surface soil source term. In modeling the surface soil source term, radiological properties are not (and cannot be) attributed to this subsurface zone because the surface soil source term is identified as the contaminated zone. Instead, because this layer underlies the surface soil contaminated zone, it is classified, in RESRAD, as an unsaturated layer. Consequently, only its physical and hydrologic properties are used to model the fate and transport of radiological contaminants originating in the overlying surface soil contaminated layer down through this layer. Since the subsurface contaminated zone and the underlying waste layer that lies directly below it are described in common physical and hydrologic properties, these two layers are combined and treated as a single layer (unsaturated layer #2) when modeling the surface soil source term.

5.2.2.4 Underlying Waste Layer

The fourth layer or zone is identified as the underlying (non-radioactive) waste layer. This layer is actually composed of as many as three different materials (depending upon the location) consisting of: 1) native soils cataloged as Belleville series soils, 2) industrial waste disposed on the site prior to placement of radioactive slag, and 3) the sand cover layer placed over the industrial wastes prior to deposition of slag on top of the sand cover. There is no credible and feasible way to adequately measure the presence or absence of these three subcomponents so that they might be described as separate layers with their own physical and hydrogeologic properties. Accordingly, MDNR has elected to conservatively describe the entire zone in terms of the physical and hydrogeologic properties that will result in the greatest potential for radioactive transport. The sand cover is the material with the lowest density and the highest hydraulic conductivity. Samples of native sand from the site were tested and found to have a soil density of 1.65 g/cm^3 and a hydraulic conductivity equivalent to 2,018 m/y. RESRAD default radionuclide distribution coefficients were used for all isotopes.

As described in Section 5.2.2.3 above, this layer is combined with the subsurface soil contaminated zone and identified as "unsaturated zone #2" in RESRAD when modeling the surface soil source term. In this case, the combined thickness of these layers is described with the RESRAD default distribution, bounded lognormal-N, having a central tendency value of 4 meters bounded at a minimum of 3 meters and a maximum of 5 meters.

When modeling the subsurface-soil source term, the underlying waste layer is treated as a distinct layer underlying the contaminated zone and is identified as "unsaturated layer #1." The thickness of the underlying waste layer is described by the RESRAD default distribution, bounded lognormal-N, with a central tendency value of 1.52 meters bounded at a minimum of 0.5 meters and a maximum of 4 meters. In this case, the thickness of unsaturated layer #1 is inversely correlated with the thickness of the subsurface soil contaminated zone, such that the most likely summed thickness of these two layers is approximately 4 meters.

5.2.2.5 Glacial Till Layer

The fifth layer is the clay-bearing native glacial till layer that underlies the site and surrounding area. The till is very dense, and is estimated to range in thickness between 50 and 100 ft. (15 to 30 meters) with a nominal or typical thickness of approximately 60 ft. (18.3 meters). RESRAD identifies this layer as "unsaturated layer #2" when modeling the subsurface soil source term and "unsaturated layer #3" when modeling the surface soil source term. The thickness of this zone is described with the RESRAD default distribution, bounded lognormal-N, having a central tendency value of 18.3 meters bounded at a minimum of 15.25 meters and a maximum of 30.5 meters. The tightly packed clay soil composition makes the soil density parameter relatively high and the hydraulic conductivity parameter low. Measured soil density is 1.97 g/cm^3 and measured hydraulic conductivity is 0.017 m/y. RESRAD default radionuclide distribution coefficients were used for all isotopes.

5.2.2.6 Deep Aquifer Layer

The lower-most (deepest) layer is described as the deep aquifer layer. It is not important from a dose modeling perspective when groundwater at the site is not used for drinking water. Still, the RESRAD model will calculate the potential for radioactive material "breakthrough" allowing the decision makers and risk managers to evaluate the potential impacts on groundwater even if the drinking water pathway is not used in a given scenario. The lower-most layer thickness is not utilized in any calculations.

5.3 DESCRIPTION OF THE EXPOSURE SCENARIOS

The third fundamental component of a dose assessment used to derive DCGLs is the conception and description of plausible and realistic human exposure scenarios. A number of physical and demographic properties pertinent to the site contribute to the conception of plausible and realistic settings in which an individual might be exposed at the site in the future.

The site is located in a vast, freshwater marsh, and is surrounded by ponded water and supersaturated soils. Other than passive recreational uses, past use of the land at the site has been limited to industrial-waste land disposal. Within the immediate vicinity of the site, development of the marshland for residential, commercial, or agricultural uses has not been undertaken. Land in the surrounding area is also largely undeveloped and is sparsely populated with a mixture of single-family residential dwellings and some small commercial facilities. There is no apparent trend in the land use in the immediate area surrounding the Site. The only noteworthy development of land in the vicinity of the site is more than 1 mile away along Highway 13. The lack of substantive land development in the immediate vicinity of the site coupled with the downward trend in population in

Bay County supports the premise that Site uses into the foreseeable future will be consistent with present uses. Land that is far more suitable for development than that which exists at the Site is available in the surrounding vicinity. The MDNR site does not have the necessary infrastructure (e.g. roadways, utilities) required to support development of the land while the area in the surrounding vicinity already has an infrastructure in place with a considerable amount of vacant land suitable for development.

As to the suitability of the land for different future uses (involving land development), a number of physical factors present significant limitations:

5.3.1 Soil Properties

U.S. Department of Agriculture, Soil Conservation Service's Soil Survey of Bay County, Michigan (USDA 1977) indicates the soil at and around the site is classified as the Belleville series. Belleville soil is characterized by a dark gray, loamy surface layer with grayish-brown sand subsoil. The substratum is multicolored clay loam and loam. Permeability is high in the sandy upper part and low in the loamy lower part. In most Belleville soil areas, and wetlands (ponded water, marsh vegetation) are present. It has potential for development as habitat for wetland wildlife. Due to the soil characteristics, other development options are economically infeasible or impractical. Belleville soils are either not suitable for growing typical agricultural products or these products are generally not grown in Belleville soils. Belleville soils have severe limitations for the following construction activities:

- shallow excavations
- dwellings with or without basements
- small commercial buildings
- local roads and streets
- lawns and landscaping

A severe limitation indicates that one or more soil properties or site features are so unfavorable or difficult to overcome that a major increase in construction effort, special design, or intensive maintenance is required. Belleville soils have severe limitations for use as sanitary facilities such as septic tank adsorption fields or sewage lagoons. Belleville soils are considered poor to unsuitable options for use as road fill, sand, gravel, or topsoil.

Soil properties of the clay cover material are likewise unsuitable for producing crops or gardens (section 5.2.2.2, Appendix J).

5.3.2 Utilities Upgrade Limitations

Currently, the site is accessed by using a perimeter road that surrounds the Waste Management landfill that is located south of the site. The remainder of the site is bordered by the Tobico Marsh State Game Area, and no roads access the site through the game area. Those desiring access will need to acquire the land, or rights to use the land, for the construction of an approximately 1-mile long access or improved road to the site. The current state of the landfill perimeter road is acceptable for sporadic, recreational use only.

Residential or commercial use of the Site would require significant widening and reconstruction of the current access road. The cost of road rehabilitation is highly dependent upon the finish material. A new 1-mile gravel road (the least expensive alternative to a paved road) built to County road standards would cost approximately $240,000. A reconstructed road or one constructed to a lesser standard would be marginally less expensive. The access road cost alone would likely cause a potential buyer to purchase land elsewhere in the area that has existing suitable access. With the price of tiled agricultural land estimated at $2,000 or less per acre (MSU 2001), the cost of road building would be prohibitive for agricultural use.

Typical low-cost drainage measures, such as seeded ditches, would be difficult to install at this site. The soil type and soil wetness would cause ditch sidewalls to slump as they are excavated, making proper excavation to required depths infeasible. Alternative ditch construction methods, including excavation shoring and concrete/riprap installation, would raise construction costs to prohibitive levels. Without adequate drainage, flooding and wetness would prohibit proper construction, operation, and maintenance of permanent structures and prevent the growing of crops. MDNR believes that the cost of drainage installation, especially when added to the capital costs of road installation, would prevent the reuse of the land for agricultural, commercial, or residential purposes.

5.3.3 Agricultural Improvement Limitations

The site presents many disadvantages that make agricultural use of the land very unlikely. The costs associated with access road construction, excavation of drainage ditches, installation of culverts, and clearing land make this property extremely unattractive to prospective farmers. It is much more likely that a buyer interested in agricultural land would purchase other land in the area that already is being used for this purpose. A 2001 land survey estimates land values in this area of Michigan at approximately $2,000 per acre for tiled agricultural land. Access road construction costs alone for this 3-acre site would far exceed the $6,000 required to purchase 3 acres of agricultural land in the surrounding area.

A soil survey (USDA 1980) indicates that the soil types at the site are some of the poorest agriculture producing soil types in Bay County. It is also unlikely that an agricultural user would purchase and develop a site for use that has a maximum production area of only 3 acres. Water well yield is traditionally low throughout the area, making installation of multiple, deep-aquifer wells for irrigation unlikely (MDEQ-Bay City).

In addition, more suitable farmland is located in the surrounding areas. Advantages to farming the surrounding area lands include:

- Soil that is more suitable for farming;
- Easier access due to an existing infrastructure;
- Less expense to "prepare" land for farming (i.e. draining); and
- Population higher in surrounding area, therefore larger "consumer base."

5.3.4 Commercial Use Limitations

Commercial use of the land would face the same infrastructure requirements as those required for agricultural use. Notable additions would be adequate power and water supply.

Frequent flooding and wetness of the site would require extensive and well-maintained drainage systems and may be cost prohibitive as well as physically prohibitive to the construction of large commercial buildings. Power supply would require the installation of approximately 1 mile of poles and wire at a current value cost of approximately $80,000. Water supply in the area is obtained from depths of approximately 150 feet below ground surface; however, low yields are common and may be a significant issue depending upon the water usage requirements of the intended commercial use. Installation of a deep well, pumps, water lines, and associated equipment would cost approximately $8,000 to $10,000. The high water table also presents problems with septic systems and required septic field sizes.

5.3.5 Residential Use Limitations

MDNR does not believe it likely that any sort of residential use would be attempted at this property. Numerous infrastructure costs make this property unattractive in comparison to other available land in the area. Also, residents of this property may be required to travel through or next to a landfill to get to the nearest public roadway. The parcel offers little aesthetic value, other than isolation, with few large trees on the perimeter and is surrounded by a wetland that provides excellent breeding sites for nuisance insects. Other disadvantages previously noted that would be applicable to residential use include power supply, water supply, drainage, and septic installation.

5.3.6 Recreational Use Limitations

Typical recreational opportunities that provide value to vacant land – access to lakes and streams – are not present at this site. With its proximity to a State Game Area, however, the site does provide a potential use for hunters. Since hunters would use the site only sporadically, they would likely avoid the development costs associated with road construction.

Beyond road access, the level of site development required by hunters would be entirely dependent upon the potential owner's desires. Placement of more permanent facilities such as a water well and/or rustic cabin would likely be more expensive at the site than at another property within the area; however, the cost of property nearer the more developed areas may be higher than at the subject site. Such developments would, however, face the same prohibitive challenges as residential reuse.

MDNR believes that recreational users would not attempt to establish permanent structures or perform excavation for any reason. If installed, water wells would, by typical yield rates and by rule, have to be screened below the contaminated zones.

Table 5-2 summarizes the advantages/disadvantages of potential land reuse at the Site.

Table 5-2 Site Land Reuse Advantages/Disadvantages

Possible Land Uses	Minimum Development Requirements	Relative Cost	Site Advantages	Site Disadvantages	Relative Likelihood
Agricultural	Access Road Construction, Site Drainage, Land Clearing, Site Work, Water Supply, Building Construction, Soil Importing and Amendments	Very High	None	Existing soil types are poor producers, flooding, wetness, small acreage, access	Extremely Low
Recreational	Access Road Construction, Site Drainage*, Land Clearing*, Site Work*, Water Supply*, Building Construction*	Moderate	Bordered by State Game Area	No lake/river recreation, limited to hunting only	Low
Commercial	Access Road Construction, Site Drainage, Land Clearing, Site Work, Water Supply, Building Construction	Very High	Railroad nearby	Site is far from existing roads, limited acreage, excavations not possible, flooding	Extremely Low
Residential	Access Road Construction, Site Drainage, Land Clearing, Site Work, Water Supply, Building Construction	Very High	Isolated	Site is far from existing roads, basements not possible, flooding, septic difficult, deep well required, access, utility infrastructure	Extremely Low
(asterisk indicates it may be optional)					

5.3.7 Exposure Scenario Selection

Based upon these limiting site physical characteristics, societal trends, and significantly unfavorable economic factors, and without regard to the multiple agency impediments to future development, MDNR considers the future use of the site for farming or residential/commercial development to be highly unlikely. However, given the potential low cost of development for recreational use, MDNR believes that it may be possible to reuse the site for publicly sponsored recreational (primarily hunting) purposes.

While hunters may be among the most likely recreational uses to be exposed at the site, it is also credible to consider that fishing may occur in the surface waters in the proximity of the site. The possibility also exists that naturalists, such as bird watchers or other nature enthusiasts, might visit the site because such activities are encouraged and supported within the Tobico Marsh State Game Area. Each of these variants on a recreational land use represents a discrete and different scenario since different exposure pathways are involved (Figure 5–8). A fourth, composite recreational land user has also been envisioned in which the recreational user engages in all three forms of recreational activity at the site. This composite receptor provides a reasonable upper bound on the potential annual radiation dose that a receptor may be exposed to while engaging in recreational activities at the site. For each scenario, the critical exposure group, the group likely to receive the greatest exposure at the site for a given scenario, is described and used in deriving the DCGL.

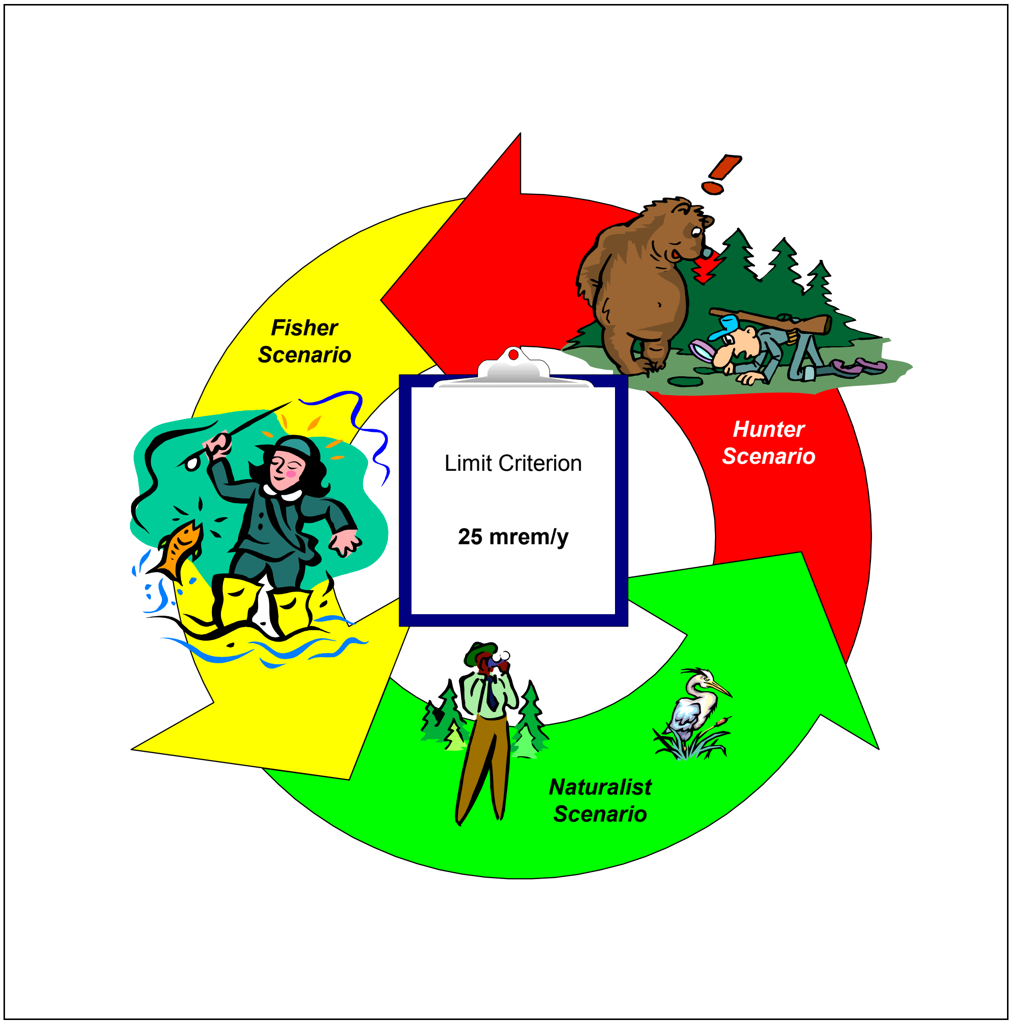

Figure 5–8 Exposure Scenarios Evaluated at the Tobico Marsh SGA

5.4 RECREATIONAL HUNTER SCENARIO

5.4.1 Description of the Critical Group

The critical exposure group for the recreational hunter scenario is described by hypothetical subpopulation that frequently hunts recreationally and consumes a considerable amount of game meat culled from the site. This hunter (as conservatively described) is likely to spend a large fraction of his available outdoor recreational time engaged in hunting and who returns to the MDNR site each time rather than visiting other sites or roaming about the vast non-impacted Tobico Marsh State Game Area lands in search of prey.

5.4.2 Pathways Included in the Recreational Hunter Scenario

Table 5-3 identifies the pathways that have been retained for the analysis and provides explanation for those pathways that were not retained.

Table 5-3 Evaluation of Pathways for the Recreational Hunter Scenario

Pathway	Retained	Remark
Direct Exposure	Yes	The source term found in the Site soils produces penetrating gamma radiation. Exposure from direct penetrating radiation is expected to be a significant contributor to the overall potential dose.
Particulate Inhalation	Yes	Allowance is made for soils containing radiological constituents of the source being liberated and suspended in the breathing air of the recreational hunter.
Radon	No	Radon is specifically excluded from consideration within the framework of the governing regulations. In addition, the source term found is not a significant producer of radon due to the relatively long half-life of the thorium isotopes found in the slag.
Plant Ingestion	No	Ingestion of plant foods addresses those plant foods grown in the radioactivity or irrigated with water containing radioactivity from on Site. Since recreational hunters are not expected to glean edible plant parts grown on site for food consumption, this pathway is incomplete.
Drinking Water	No	Surface water on site is unfit for consumption as drinking water. No on-site sources of groundwater have been developed for drinking water.
Meat Ingestion	Yes	Recreational hunters are expected to consume meat from animals culled from the site.
Milk Ingestion	No	Milk ingestion pathway is incomplete since it is not credible to consider that recreational hunters would graze milk cows on this Site.
Aquatic Foods Ingestion	No	Recreational hunters are not expected to spend time fishing the surface water bodies surrounding the Site.
Direct Ingestion	Yes	Hunters on the Site may ingest relatively small amounts of soil through incidental oral contact with their hands.

5.4.3 Description of the Parameters Used in the Analysis

The recreational hunter scenario involves relatively conservative exposure factors attributable to members of the critical group, hunting enthusiasts, who may spend a considerable amount of time hunting and whose annual diet of meat is composed of a large fraction of game culled from the site. Key parameters used to define the recreational hunter exposure scenario are presented in a series of three tables along with specific remarks explaining the values' selection[6]. The tables are organized such that key parameters common to the assessment of both the surface and subsurface soil source terms are presented first. Subsequent tables present key parameters that are unique to each of the two source terms. Table 5-4 contains common parameters describing the receptor's exposure and behavioral patterns (e.g., exposure time, inhalation rate, etc.) as well as common parameters describing the general and weather-related parameters relevant to the site. Table 5-5 contains parameters specific to the surface soil source term (i.e., geotechnical parameters and parameters describing the source term itself) while Table 5-6 contains parameters specific to the subsurface soil source term.

6 A comprehensive list of the input parameters used in the execution of the RESRAD dose modeling code to evaluate the potential future radiation dose for each scenario is provided in the RESRAD output files (reports) in appendices A–H.

Table 5-4 Key Common Parameters—Recreational Hunter Scenario

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Receptor Exposure Factors						
Exposure Frequency (Total)	EF	Days per year	25	EF and ET are not input parameters used by RESRAD. They are presented here to disclose the calculation used to arrive at the parameters RESRAD uses to account for exposure frequency, FIND & FOTD.		Assumes weeks per year of time spent hunting specifically on the Tobico Site.
Exposure Time	ET	Hours per Day	10			Conservatively assumes that each day spent hunting on site is 10-hours long.
Indoor Time Fraction	FIND	Unitless, 0 to 1	0	Point estimate		The fraction of a total year (8760 hr) that is spent indoors on Site. Assumes that all exposures occur outdoors. There are no habitable structures on the site.
Outdoor Time Fraction	FOTD	Unitless, 0 to 1	0.0285	Triangular	Range: 0 to 0.057	The fraction of a total year (8760 hr) that is spent outdoors on Site. Equals 250 hrs outdoors on Site divided by 8760 hours. The probabilistic distribution ranges to twice the CT value (500 hrs per year spent hunting on the site).
Inhalation Rate	INHALR	m^3/yr	8400	Triangular	Range: 4380 to 13100	RESRAD Default (Yu 2001). Inhalation rate based on geometric mean rate for short-term exposure to adult males (EPA 1997a).
Contaminated Fraction of Meat	FMEAT	Unitless, 0 to 1	0.3	Triangular	Range: 0 to 0.5	The fraction of the annual meat diet that is obtained from game harvested from off the site. The number is conservative in that the size of the site is small relative to the grazing land required to support game habitat. The use of the triangular distribution results in a more conservative estimate than does the RESRAD default for this site (EPA 1997b).

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Mass Loading for Inhalation	MLINH	g/m^3	0.00003	Continuous Linear	0.000000: 0.0000 0.000008: 0.0151 0.000016: 0.1365 0.000030: 0.8119 0.000040: 0.9495 0.000060: 0.9937 0.000076: 0.9983 0.000100: 1.0000	RESRAD Default. Mass loading in air describes the airborne dust loading conditions on the Site (Yu 2001).
Soil Ingestion Rate	SOIL	g/y	18.3	Triangular	Range: 0 to 36.5	RESRAD Default. USEPA default value for adults engaged in non-contact intensive activities (50 mg/day). (Yu 2001, EPA 1997a).
Site General and Weather Related Parameters						
Evapotranspiration Coefficient	EVAPTR	Unitless, 0 to 1	0.625	Uniform	Range: 0.5 to 0.75	RESRAD Default. Typical values in humid climates east of the Mississippi River are approximately 0.7 (Yu 2001).
Average Annual Wind Speed	WIND	m/sec	4.25	Bounded Lognormal-N	μ Normal: 1.445 σ Normal: 0.2419 Min: 1.4 Max: 13.0	RESRAD Default. The five-year (1987-1991) site-specific annual average value (4.18 m/s) is nearly equal to the RESRAD default value (NOAA).
Precipitation Rate	PRECIP	m/year	0.71	Point Estimate		Annual average in Midland–Bay City–Saginaw area. Equals 28 inches per year (NOAA).
Irrigation Rate	RI	m/year	0.0	Point Estimate		No irrigation is considered in the future uses of the site.
Runoff Coefficient	RUNOFF	Unitless, 0 to 1	0.45	Uniform	Range: 0.1 to 0.8	The fraction of total annual precipitation that sheds off the surface and drains to Site watershed drainage without percolating through the soil. Typical value is approximately 0.3 to 0.5, but is likely much higher for the Tobico Site due to the topography, drainage features of the Site, and engineered clay cover which has a very low hydraulic conductivity (Yu 2001).

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Watershed Area for Nearby Stream or Pond	WAREA	m	10000	Point Estimate		RESRAD Default. The watershed area is used to calculate dilution factors for contaminant concentrations in surface water bodies in the vicinity of the site. The watershed area for the Tobico Marsh is vastly larger than the default (it includes the entire Saginaw Bay watershed) making the default conservative (Yu 2001).
Depth of Soil Mixing Layer	DM	m	0.15	Triangular	Range: 0 to 0.6	RESRAD Default (Yu 2001).
Calculation Times	T(n)	Yrs.	0 1 10 30 100 300 1000	NA		Evaluation at these time segments allows for consideration of the potential for conditions at the Site to evolve from the initial conditions specified (e.g., soil erosion impacts the cover thickness) and projects the changing Site conditions to the required 1000-year outlook (NRC 1997a, NRC 2000).

Table 5-5 Key Parameters, Surface Soil Source Term Model—Recreational Hunter Scenario

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	**Code**	**Unit**		**Distribution**	**Range & Fit**	
Geotechnical Parameters—Surface Soil Contaminated Zone						
Area of Contaminated Zone	AREA	m^2	57.3	Triangular	Range: 0 to 5730	Most likely area (57.3 m^2) conservatively derives from the subsurface soil characterization survey findings (Cabrera 2001). There, only 14% of the 400 coreholes had measurable radioactivity distinguishable from background. Assuming that the potentially impacted area surrounding a corehole is, on average, 1 m^2, and that the surface around each of the coreholes in which elevated radioactivity was detected is actually impacted, 57.3 m^2 corresponds to a likely maximum areal size. The absolute maximum area corresponds to the entire footprint of the cell within the slurry walls. See Section 5.2.1.2
Thickness of Contaminated Zone	THICK0	m	0.001	Triangular	Range: 0 to 0.02	The contaminated zone thickness derives from the limited volume of material that could have been brought to the surface during characterization surveys. Because the maximum volume is fixed and limited, the contaminated zone thickness and area are inversely correlated and dependent upon each other. See Section 5.2.1.2
Contaminated Zone Density	DENSCZ	g/cm^3	1.97	Point Estimate		The measured density for clay-bearing materials present at the Site (Cabrera 2001).

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Contaminated Zone Erosion Rate	VCZ	m/yr	0.000003	Point Estimate		The RESRAD default surface soil erosion rate is 0.001 m/y. MDNR has chosen to conservatively represent the soil erosion rate with a single point estimate value more than 300 times lower than the default. This value corresponds with typical values for soil erosion at sites in humid areas, with a 2% slope, and natural succession vegetation (Yu 1993).
Contaminated Zone Total Porosity	TPCZ	Unitless, 0 to 1	0.4	Point Estimate		RESRAD Default (Yu 2001).
Contaminated Zone Field Capacity	FCCZ	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).
Contaminated Zone Hydraulic Conductivity	HCCZ	m/yr	10	Point Estimate		RESRAD Default (Yu 2001).
Contaminated Zone B-Parameter	BCZ	Unitless	5.3	Point Estimate		RESRAD Default (Yu 2001).

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
K_d (Thorium)	DCACTC (n)	cm^3/g	60000	Bounded Lognormal-N	μ Normal: 11.0 σ Normal: 1.0 min: 3200 max: 89000	Classically, K_d is an expression of the sorption characteristics of a soil saturated with a soluble (e.g., thorium) material in solution. This would assume, in this case, that the thorium in the source term is completely solvent, a condition not present at the site. The use of an effective or desorption K_d for thorium is warranted. The physical and chemical characteristics of the thorium bearing slag materials disposed at the Site are: 1. Thorium is not very soluble, and 2. Radionuclides do not readily leach from the slag matrix. These factors support the use of much higher values of K_d than might be found in literature searches or bench testing of soil samples using standard methods. Still, a K_d value for thorium in the Contaminated Zone of 60,000 (the RESRAD deterministic module default) is conservatively recommended as the median value, bounded with the highest and lowest geometric mean values from literature (Yu 1993) .
K_d (Lead)	DCACTC (n)	cm^3/g	100	Point Estimate		RESRAD Default (Yu 2001).
K_d (Radium)	DCACTC (n)	cm^3/g	70	Point Estimate		RESRAD Default (Yu 2001).

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Depth of Roots	DROOT	m	0.15	Lognormal-N	μ Normal: -1.9 σ Normal: 0.6	The engineered clay cover layer underlying the surface soil contaminated zone is composed of dense clay material and is designed to shed water. It does not readily support a typical plant root zone. To resist surface soil erosion, a thin (≈6 inch) layer of soil was placed over the cover and seeded with native grasses. The root depth is nominally limited to the 0.15 m (6 in.) thickness of the seeded soil layer. The fit of the lognormal-N distribution allows for root depths of up to approximately 1 meter.
Geotechnical Parameters—Unsaturated Layer #1 (Engineered Clay Cover)						
Thickness, Unsaturated Zone 1	H(1)	m	1.52	Triangular	Range: 1 to 2	From geotechnical logging performed in support of the scoping and characterization surveys, the engineered clay cover is shown to be between 1 and 2 meters (4 to 7 feet) thick over the portion of the cap circumscribed by the slurry walls. It has a typical thickness of approximately 1.52 meters (5 ft)
Density, Unsaturated Zone 1	DENSUZ (1)	g/cm^3	1.97	Point Estimate		Measured density for clay-bearing materials present at the Site (Cabrera 2001).
Total Porosity, Unsaturated Zone 1	TPUZ(1)	Unitless, 0 to 1	0.4	Point Estimate		RESRAD Default (Yu 2001).
Effective Porosity, Unsaturated Zone 1	EPUZ(1)	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).
Field Capacity Unsaturated Zone 1	FCUZ(1)	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Hydraulic Conductivity Unsaturated Zone 1	HCUZ(1)	m/yr	0.017	Bounded Lognormal-N	μ Normal: -4.08 σ Normal: 0.75 min: 0.0017 max: 0.17	The central tendency value, 0.017 m/yr (5.4E-8 cm/sec), corresponds to the measured hydraulic conductivity in native clay bearing soils found at the site. The value is assumed to range over two orders of magnitude from 0.0017 to 0.17 m/yr (Cabrera 2001).
Unsaturated Zone 1, B-Parameter	BUZ(1)	Unitless	5.3	Point Estimate		RESRAD Default (Yu 2001).
K_d (Thorium)	DCUCTU1 (n)	cm^3/g	5885	Lognormal-N	μ Normal: 8.68 σ Normal: 3.62	RESRAD Default (Yu 2001).
K_d (Lead)	DCUCTU1 (n)	cm^3/g	100	Point Estimate		RESRAD Default (Yu 2001).
K_d (Radium)	DCUCTU1 (n)	cm^3/g	70	Point Estimate		RESRAD Default (Yu 2001).
Geotechnical Parameters—Unsaturated Layer #2 (Waste Layer)						
Thickness, Unsaturated Zone 2	H(2)	m	4	Bounded Lognormal-N	μ Normal: 1.39 σ Normal: 0.25 Min: 3.0 Max: 5.0	Site characterization data indicates that the typical thickness of the layer lying between the engineered clay cover and the underlying glacial till layer is approximately 4 meters (13-15 ft.), (Cabrera 2001). To conservatively accommodate the localized variability in the thickness of this layer, the thickness has been modeled to range from 3 to 5 meters.
Density, Unsaturated Zone 2	DENSUZ (2)	g/cm^3	1.65	Point Estimate		The density is assumed to be equal to the density of native sand materials present at the Site (Cabrera 2001).
Total Porosity, Unsaturated Zone 2	TPUZ(2)	Unitless, 0 to 1	0.4	Point Estimate		RESRAD Default (Yu 2001).

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Effective Porosity, Unsaturated Zone 2	EPUZ(2)	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).
Field Capacity Unsaturated Zone 2	FCUZ(2)	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).
Hydraulic Conductivity Unsaturated Zone 2	HCUZ(2)	m/yr	2000	Bounded Lognormal-N	μ Normal: 7.6 σ Normal: 0.75 min: 200 max: 20000	The central tendency value, 2,000 m/yr (6.4E-3 cm/sec), corresponds to the measured hydraulic conductivity in sandy soils found at the site. The value is assumed to range over two orders of magnitude from 200 to 20,000 m/yr (Cabrera 2001).
Unsaturated Zone 2, B-Parameter	BUZ(2)	Unitless	5.3	Point Estimate		RESRAD Default (Yu 2001).
K_d (Thorium)	DCUCTU2 (n)	cm^3/g	5885	Lognormal-N	μ Normal: 8.68 σ Normal: 3.62	RESRAD Default (Yu 2001).
K_d (Lead)	DCACTU2 (n)	cm^3/g	100	Point Estimate		RESRAD Default (Yu 2001).
K_d (Radium)	DCACTU2 (n)	cm^3/g	70	Point Estimate		RESRAD Default (Yu 2001).
Geotechnical Parameters—Unsaturated Layer #3 (Glacial Till Layer)						
Thickness, Unsaturated Zone 3	H(3)	m	18.3	Bounded Lognormal-N	μ Normal: 2.9 σ Normal: 0.25 Min: 15.25 Max: 30.5	Local geotechnical logging indicates that the clay bearing glacial till layer is 50 to 100 feet in thickness with a typical thickness of approximately 60 feet. The slurry walls are keyed into the undisturbed native clay-bearing till layer to form a cell that contains the waste.

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Density, Unsaturated Zone 3	DENSUZ (3)	g/cm^3	1.97	Point Estimate		Unsaturated Zone 3 is the undisturbed native till layer underlying the entire site. The density is measured to be 1.97 g/cm^3 (Cabrera 2001).
Total Porosity, Unsaturated Zone 3	TPUZ(3)	Unitless, 0 to 1	0.4	Point Estimate		RESRAD Default (Yu 2001).
Effective Porosity, Unsaturated Zone 3	EPUZ(3)	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).
Field Capacity Unsaturated Zone 3	FCUZ(3)	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).
Hydraulic Conductivity Unsaturated Zone 3	HCUZ(3)	m/yr	0.017	Bounded Lognormal-N	μ Normal: -4.08 σ Normal: 0.75 min: 0.0017 max: 0.17	The central tendency value, 0.017 m/yr (5.4E-8 cm/sec), corresponds to the measured hydraulic conductivity in native clay bearing soils found at the site. The value is assumed to range over two orders of magnitude from 0.0017 to 0.17 m/yr (Cabrera 2001).
Unsaturated Zone 3, B-Parameter	BUZ(3)	Unitless	5.3	Point Estimate		RESRAD Default (Yu 2001).
K_d (Thorium)	DCACTU3 (n)	cm^3/g	5885	Lognormal-N	μ Normal: 8.68 σ Normal: 3.62	RESRAD Default (Yu 2001).
K_d (Lead)	DCACTU3 (n)	cm^3/g	100	Point Estimate		RESRAD Default (Yu 2001).
K_d (Radium)	DCACTU3 (n)	cm^3/g	70	Point Estimate		RESRAD Default (Yu 2001).
Geotechnical Parameters—Saturated Zone (Deep Aquifer)						

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Density, Saturated Zone	DENSAQ	g/cm^3	1.65	Point Estimate		The density is assumed to be equal to the density of native sand materials present at the Site (Cabrera 2001).
Total Porosity, Saturated Zone	TPSZ	Unitless, 0 to 1	0.4	Point Estimate		RESRAD Default (Yu 2001).
Effective Porosity, Saturated Zone	EPSZ	Unitless, 0 to 1	0.35	Point Estimate		Value is equal to the mean (central tendency value) used in the RESRAD Default probabilistic distribution (Yu 2001).
Field Capacity, Saturated Zone	FCSZ	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).
Hydraulic Conductivity, Saturated Zone	HCSZ	m/yr	10	Bounded Lognormal-N	μ Normal: 2.3 σ Normal: 2.11 min: 0.004 max: 9250	RESRAD Default (Yu 2001).
Hydraulic Gradient	HGWT	Unitless	0.02	Point Estimate		RESRAD Default (Yu 2001).
Saturated Zone B-Parameter	BSZ	Unitless	5.3	Point Estimate		RESRAD Default (Yu 2001).
Source Term Factors						
Dose Conversion Factors	DCFX(n)	mrem/pCi	All DCFs used are RESRAD defaults			RESRAD defaults from FGR #11 (EPA 1988a) and FGR #12 (EPA 1993) and are derived using ICRP 30 dosimetry model. Short-lived (<180 days) radioactive progeny isotopes are accounted for through the use of the "parent+D" DCFs.
Source Isotopes			Thorium-bearing Slag Isotopic Mix (% of total activity)			This isotopic mix is derived from Site-specific data and assumes that the volume weighted average Th-230:232 ratio is 3.1:1 as calculated.
Pb-210	S1(1)	pCi/g	11.1	Point Estimate	0.5%	

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Ra-226	S1(2)	pCi/g	24.4	Point Estimate	1.1%	The typically observed ratio during characterization sampling was found to be approximately 1:1, but as noted, two discrete locations exhibited ratios of approximately 10:1 (Cabrera 2001). Even if a conservative 10:1 ratio were used to define the expected radionuclide profile in the mixture, the source term would be limited by the specific activity limit of Th-232. Ra-226 and Pb-210 activities are derived from 50-year ingrowth calculations and exhibit good agreement with measured ratios. All percentages calculated as the fraction of total activity of radionuclides in the mixture with half-lives greater than 180 days.
Ra-228	S1(3)	pCi/g	356.9	Point Estimate	16.1%	
Th-228	S1(4)	pCi/g	356.9	Point Estimate	16.1%	
Th-230	S1(5)	pCi/g	1108.5	Point Estimate	50.0%	
Th-232	S1(6)	pCi/g	356.9	Point Estimate	16.1%	
A comprehensive list of the input parameters used in the execution of the RESRAD dose modeling code to evaluate the potential future radiation dose for the Recreational Hunter Scenario is provided in the RESRAD output files (reports) in Appendix E for the surface soil source term.						

Table 5-6 Key Parameters, Subsurface Soil Source Term Model—Recreational Hunter Scenario

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Geotechnical Parameters—Cover Layer (Engineered Clay Cover)						
Cover Depth (thickness)	COVER0	m	1.52	Triangular	Range: 1 to 2	From geotechnical logging performed in support of the scoping and characterization surveys, the engineered clay cover is shown to be between 1 and 2 meters (4 to 7 feet) thick over the portion of the cap circumscribed by the slurry walls. It has a typical thickness of approximately 1.52 meters (5 ft)
Cover Density	DENSCV	g/cm^3	1.97	Truncated Normal	μ Normal: 1.97 σ Normal: 0.23 Quantile, min: 0.05 Quantile, max: 0.95	Measured density for clay-bearing materials present at the Site (Cabrera 2001).
Cover Erosion Rate	VCV	m/yr	0.000003	Continuous Logarithmic	0.0000008 0.00 0.000003 0.50 0.00006 1.00	Typical value for soil erosion rates for sites in humid areas, with a 2% slope, and natural succession vegetation are estimated to range between 8 x 10^{-7} and 3 x 10^{-6} m/y (based on model site calculations using the Universal Soil Loss Equation method. MDNR has allowed the soil erosion rate to range to a maximum value of 6 x 10^{-5} m/y, the highest cited value recommended for use in RESRAD (Yu 1993) for a site with 2% slope and for which it can be reasonably shown that the site is, and will continue to be, unsuitable for agricultural use.

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Depth of Roots	DROOT	m	0.15	Lognormal-N	μ Normal: -1.9 σ Normal: 0.6	The engineered cover is composed of dense clay material that is designed to shed water. It does not readily support a typical plant root zone. To further resist erosion, a thin (≈6 inch) layer of soil was placed over the cover and seeded with native grasses. The root depth is nominally limited to the 0.15 m (6 in.) thickness of the seeded soil layer. The fit of the lognormal-N distribution allows for root depths of up to approximately 1 meter.
Geotechnical Parameters—Subsurface Soil Contaminated Zone						
Area of Contaminated Zone	AREA	m^2	791	Loguniform	Range: 791 to 5725	Most likely area corresponds to the area in which elevated radioactivity was detected during characterization surveys. The maximum area corresponds to the entire footprint of the cell within the slurry walls (Cabrera 2001).
Thickness of Contaminated Zone	THICK0	m	1.22	Bounded Lognormal-N	μ Normal: 0.20 σ Normal: 0.75 Min: 0.3 Max: 3.0	Site characterization data indicates that the residual radioactivity in soil lies below the thickness of the cover and generally terminates at a thickness of approximately 1.22 meters (4 ft.). To accommodate the localized variability in the depth of contamination, the source term thickness has been modeled to range from 0.3 to 3.0 meters (Cabrera 2001).
Contaminated Zone Density	DENSCZ	g/cm^3	1.65	Truncated Normal	μ Normal: 1.65 σ Normal: 0.23 Quantile, min: 0.05 Quantile, max: 0.95	The Contaminated Zone Density is assumed to be equal to the density of native sand materials present at the Site (Cabrera 2001).
Contaminated Zone Erosion Rate	VCZ	m/yr	0.000003	Continuous Logarithmic	0.0000003 0.00 0.000003 0.25 0.00003 0.50 0.0003 0.75 0.003 1.00	The same erosion rate predicted for the cover is conservatively used for the Contaminated Zone.

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Contaminated Zone Total Porosity	TPCZ	Unitless, 0 to 1	0.4	Point Estimate		RESRAD Default (Yu 2001).
Contaminated Zone Field Capacity	FCCZ	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).
Contaminated Zone Hydraulic Conductivity	HCCZ	m/yr	2000	Bounded Lognormal-N	μ Normal: 7.6 σ Normal: 0.75 min: 200 max: 20000	The central tendency value, 2,000 m/yr (6.4E-3 cm/sec), corresponds to the measured hydraulic conductivity in sandy soils found at the site. The value is assumed to range over two orders of magnitude from 200 to 20,000 m/yr (Cabrera 2001).
Contaminated Zone B-Parameter	BCZ	Unitless	2.88	Bounded Lognormal-N	μ Normal: 1.06 σ Normal: 0.66 min: 0.5 max: 30	RESRAD Default (Yu 2001).

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
K_d (Thorium)	DCACT (n)	cm^3/g	60000	Bounded Lognormal-N	μ Normal: 11.0 σ Normal: 1.0 min: 3200 max: 89000	Classically, K_d is an expression of the sorption characteristics of a soil saturated with a soluble (e.g., thorium) material in solution. This would assume, in this case, that the thorium in the source term is completely soluble, a condition not present at the site. The use of an effective or desorption K_d for thorium is warranted. The physical and chemical characteristics of the thorium bearing slag materials disposed at the Site are: 3. Thorium is not very soluble, and 4. Radionuclides do not readily leach from the slag matrix. These factors support the use of much higher values of K_d than might be found in literature searches or bench testing of soil samples using standard methods. Still, a K_d value for thorium in the Contaminated Zone of 60,000 (the RESRAD deterministic module default) is conservatively recommended as the median value, bounded with the highest and lowest geometric mean values from literature (Yu 1993) .
K_d (Lead)	DCACT (n)	cm^3/g	100	Point Estimate		RESRAD Default (Yu 2001).
K_d (Radium)	DCACT (n)	cm^3/g	70	Point Estimate		RESRAD Default (Yu 2001).

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Geotechnical Parameters—Unsaturated Layer #1 (Underlying Waste Layer)						
Thickness, Unsaturated Layer 1	H1	m	1.22	Bounded Lognormal-N	μ Normal: 0.42 σ Normal: 0.5 Min: 0.5 Max: 4.0	Site characterization data indicates that the typical depth from just below the cover to the interface of the native clay-bearing till layer is approximately 2.75 m (9 ft) with some variability observed. Maximum depth observed was approximately 4 meters (14 ft.). This total thickness is shared by the contaminated layer and the uppermost unsaturated layer with the two thicknesses being inversely correlated with each other (Cabrera 2001).
Density, Unsaturated Layer 1	DENSUZ (1)	g/cm^3	1.65	Truncated Normal	μ Normal: 1.65 σ Normal: 0.23 Quantile, min: 0.05 Quantile, max: 0.95	Unsaturated Zone 1 is the sand cover layer placed over the site prior to disposal of thorium bearing slag. The density is assumed to be equal to the density of native sand materials present at the Site (Cabrera 2001).
Total Porosity, Unsaturated Layer 1	TPUZ(1)	Unitless, 0 to 1	0.4	Point Estimate		RESRAD Default (Yu 2001).
Effective Porosity of Unsaturated Layer 1	EPUZ(1)	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).
Field Capacity Unsaturated Layer 1	FCUZ(1)	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).
Hydraulic Conductivity Unsaturated Layer 1	HCUZ(1)	m/yr	2000	Bounded Lognormal-N	μ Normal: 7.6 σ Normal: 0.75 min: 200 max: 20000	The central tendency value, 2000 m/yr (6.4E-3 cm/sec), corresponds to the measured hydraulic conductivity in sandy soils found at the site. The value is assumed to range over two orders of magnitude from 200 to 20000 m/yr (Cabrera 2001).
Unsaturated Layer 1, B-Parameter	BUZ(1)	Unitless	5.3	Point Estimate		RESRAD Default (Yu 2001).

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
K_d (Thorium)	DCACTU1 (n)	cm^3/g	5885	Lognormal-N	μ Normal: 8.68 σ Normal: 3.62	RESRAD Default (Yu 2001).
K_d (Lead)	DCACTU1 (n)	cm^3/g	100	Point Estimate		RESRAD Default (Yu 2001).
K_d (Radium)	DCACTU1 (n)	cm^3/g	70	Point Estimate		RESRAD Default (Yu 2001).
Geotechnical Parameters—Unsaturated Layer #2 (Glacial Till Layer)						
Thickness, Unsaturated Layer 2	H(2)	m	18.3	Bounded Lognormal-N	μ Normal: 2.9 σ Normal: 0.25 Min: 15.25 Max: 30.5	Local geotechnical logging indicates that the clay bearing glacial till layer is 50 to 100 feet in thickness with a typical thickness of approximately 60 feet. The slurry walls are keyed into the undisturbed native clay-bearing till layer to form a cell that contains the waste.
Density, Unsaturated Layer 2	DENSUZ (2)	g/cm^3	1.97	Truncated Normal	μ Normal: 1.97 σ Normal: 0.23 Quantile, min: 0.05 Quantile, max: 0.95	Unsaturated Zone 2 is the undisturbed native till layer underlying the entire site. The density is measured to be 1.97 g/cm^3 (Cabrera 2001).
Total Porosity, Unsaturated Layer 2	TPUZ(2)	Unitless, 0 to 1	0.4	Point Estimate		RESRAD Default (Yu 2001).
Effective Porosity, Unsaturated Layer 2	EPUZ(2)	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).
Field Capacity Unsaturated Layer 2	FCUZ(2)	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Hydraulic Conductivity Unsaturated Layer 2	HCUZ(2)	m/yr	0.017	Bounded Lognormal-N	μ Normal: -4.08 σ Normal: 0.75 min: 0.0017 max: 0.17	The central tendency value, 0.017 m/yr (5.4E-8 cm/sec), corresponds to the measured hydraulic conductivity in native clay bearing soils found at the site. The value is assumed to range over two orders of magnitude from 0.0017 to 0.17 m/yr (Cabrera 2001).
Unsaturated Layer 2, B-Parameter	BUZ(2)	Unitless	5.3	Point Estimate		RESRAD Default (Yu 2001).
K_d (Thorium)	DCACTU2 (n)	cm^3/g	5885	Lognormal-N	μ Normal: 8.68 σ Normal: 3.62	RESRAD Default (Yu 2001).
K_d (Lead)	DCACTU2 (n)	cm^3/g	100	Point Estimate		RESRAD Default (Yu 2001).
K_d (Radium)	DCACTU2 (n)	cm^3/g	70	Point Estimate		RESRAD Default (Yu 2001).
Geotechnical Parameters—Saturated Zone (Deep Aquifer)						
Density, Saturated Zone	DENSAQ	g/cm^3	1.52	Truncated Normal	μ Normal: 1.52 σ Normal: 0.23 Quantile, min: 0.001 Quantile, max: 0.999	RESRAD Default (Yu 2001).
Total Porosity, Saturated Zone	TPSZ	Unitless, 0 to 1	0.4	Point Estimate		RESRAD Default (Yu 2001).
Effective Porosity, Saturated Zone	EPSZ	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).
Field Capacity, Saturated Zone	FCSZ	Unitless, 0 to 1	0.2	Point Estimate		RESRAD Default (Yu 2001).

Parameter: Description	Parameter: Code	Parameter: Unit	Central Tendency Value	Description of Parameter Distribution: Distribution	Description of Parameter Distribution: Range & Fit	Remark
Hydraulic Conductivity, Saturated Zone	HCSZ	m/yr	10	Bounded Lognormal-N	μ Normal: 2.3 σ Normal: 2.11 min: 0.004 max: 9250	RESRAD Default (Yu 2001).
Hydraulic Gradient	HGWT	Unitless	0.006	Bounded Lognormal-N	μ Normal: -5.11 σ Normal: 1.77 min: .00007 max: 0.5	RESRAD Default (Yu 2001).
Saturated Zone B-Parameter	BSZ	Unitless	2.88	Bounded Lognormal-N	μ Normal: 1.06 σ Normal: 0.66 min: 0.5 max: 30	RESRAD Default (Yu 2001).
Source Term Factors						
Dose Conversion Factors	DCFX(n)	mrem/pCi	All DCFs used are RESRAD defaults			RESRAD defaults from FGR #11 (EPA 1988a) and FGR #12 (EPA 1993) and are derived using ICRP 30 dosimetry model. Short-lived (<180 days) radioactive progeny isotopes are accounted for through the use of the "parent+D" DCFs.
Source Isotopes			Thorium-bearing Slag Isotopic Mix (% of total activity)			This isotopic mix is derived from Site-specific data and assumes that the volume weighted average Th-230:232 ratio is 3.1:1 as calculated. The typically observed ratio during characterization sampling was found to be approximately 1:1, but as noted, two discrete locations exhibited ratios of approximately 10:1 (Cabrera 2001). Even if a wildly conservative 10:1 ratio were used to define the expected radionuclide profile in the mixture, the source term would be limited by the specific activity
Pb-210	S1(1)	pCi/g	3.4E3	Point Estimate	0.5%	
Ra-226	S1(2)	pCi/g	7.48E3	Point Estimate	1.1%	
Ra-228	S1(3)	pCi/g	1.09E5	Point Estimate	16.1%	
Th-228	S1(4)	pCi/g	1.09E5	Point Estimate	16.1%	
Th-230	S1(5)	pCi/g	3.40E5	Point Estimate	50.0%	

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Th-232	S1(6)	pCi/g	1.09E5	Point Estimate	16.1%	limit of Th-232. Ra-226 and Pb-210 activities are derived from 50-year ingrowth calculations and exhibit good agreement with measured ratios. All percentages calculated as the fraction of total activity of radionuclides in the mixture with half-lives greater than 180 days.
A comprehensive list of the input parameters used in the execution of the RESRAD dose modeling code to evaluate the potential future radiation dose for the Recreational Hunter Scenario is provided in the RESRAD output files (reports) in Appendix A for the subsurface soil source term.						

5.5 NATURALIST SCENARIO

5.5.1 Description of the Critical Group

The critical exposure group for the naturalist scenario is described by a hypothetical subpopulation that frequently visits the site to observe the natural surroundings (e.g., bird watching). The naturalist is assumed to consume some edible plants or berries that may be growing wild on the site. This naturalist (as conservatively described) is likely to spend a large fraction of his available outdoor recreational time engaged in nature viewing and returns to the MDNR site each time rather than visiting other sites or roaming about the vast non-impacted Tobico Marsh State Game Area lands in search of other spots from which to enjoy to the natural surroundings.

5.5.2 Pathways Included in the Naturalist Scenario

Table 5-7 identifies the pathways that have been retained for the analysis and provides explanation for those pathways that were not retained.

Table 5-7 Evaluation of Pathways for the Naturalist Scenario

Pathway	Retained	Remark
Direct Exposure	Yes	The source term found in the Site soils produces penetrating gamma radiation. Exposure from direct penetrating radiation is expected to be a significant contributor to the overall potential dose.
Particulate Inhalation	Yes	Allowance is made for soils containing radiological constituents of the source being liberated and suspended in the breathing air of the naturalist.
Radon	No	Radon is specifically excluded from consideration within the framework of the governing regulations. In addition, the source term found is not a significant producer of radon due to the relatively long half-life of the thorium isotopes found in the slag.
Plant Ingestion	Yes	Ingestion of plant foods addresses those plant foods grown in the radioactivity or irrigated with water containing radioactivity from on Site. Naturalist visitors to the site may conceivably consume edible plant parts grown on site.
Drinking Water	No	Surface water on site is unfit for consumption as drinking water. No on site sources of groundwater have been developed for drinking water.
Meat Ingestion	No	Naturalists are not expected to consume meat from game animals culled from the site.
Milk Ingestion	No	Milk ingestion pathway is incomplete since it is not credible to consider that milk cows would graze on this Site.
Aquatic Foods Ingestion	No	Naturalists are not expected to spend time fishing the surface water bodies surrounding the Site.

Direct Ingestion	Yes	Naturalists on the site may ingest relatively small amounts of soil through incidental oral contact with their hands.

5.5.3 Description of the Parameters Used in the Analysis

The naturalist scenario involves relatively conservative exposure factors attributable to members of the critical group, nature enthusiasts, who spend a considerable amount of time observing the natural surroundings and who, while visiting, consume plant food gleaned from wild plants growing on the site. Key parameters used to define the naturalist exposure scenario are presented in Table 5-8 along with specific remarks explaining the values' selection. Table 5-8 contains only the key parameters describing the naturalist's exposure and behavioral patterns (e.g., exposure time, inhalation rate, etc.) as all of the other site parameters—those describing the site in general, its weather, the geotechnical or physical abstraction, and the source term itself—are unchanged from those identified for the recreational hunter and presented in Table 5-5 and Table 5-6.

Table 5-8 Key Parameters—Naturalist Scenario

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Receptor Exposure Factors						
Exposure Frequency (Total)	EF	Days per year	25	EF and ET are not input parameters used by RESRAD. They are presented here to disclose the calculation used to arrive at the parameters RESRAD uses to account for exposure frequency, FIND & FOTD.		Assumes 25 days per year spent viewing nature specifically on the Tobico Site.
Exposure Time	ET	Hours per Day	10			Conservatively assumes that each day spent on site is 10-hours long.
Indoor Time Fraction	FIND	Unitless, 0 to 1	0	Point estimate		The fraction of a total year (8760 hr) that is spent indoors on Site. Assumes that all exposures occur outdoors. There are no habitable structures on the site.
Outdoor Time Fraction	FOTD	Unitless, 0 to 1	0.0285	Triangular	Range: 0 to 0.057	The fraction of a total year (8760 hr) that is spent outdoors on Site. Equals 250 hrs outdoors on Site divided by 8760 hours. The probabilistic distribution ranges to twice the CT value (500 hrs per year spent viewing nature on the site).
Inhalation Rate	INHALR	m^3/yr	8400	Triangular	Range: 4380 to 13100	RESRAD Default. Inhalation rate based on geometric mean rate for short-term exposure to adult males (EPA 1997a, Yu 2001).
Contaminated Fraction of Plant Food	FPLANT	Unitless, 0 to 1	0.0285	Triangular	Range: 0 to 0.057	The fraction of the annual plant foods diet that is obtained from edible, natural succession vegetation grown on the site. The fraction is consistent with the time spent on site but is thought to be very conservative in that it assumes that a relatively large, naturally sustainable, and edible plant population is present on the cover of the cell. As described earlier, the soil cover over the engineered clay cap is very thin and does not readily support native plants aside from grasses.

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Mass Loading for Inhalation	MLINH	g/m^3	0.00003	Continuous Linear	0.000000: 0.0000 0.000008: 0.0151 0.000016: 0.1365 0.000030: 0.8119 0.000040: 0.9495 0.000060: 0.9937 0.000076: 0.9983 0.000100: 1.0000	RESRAD Default. Mass loading in air describes the airborne dust loading conditions on the Site. The RESRAD default CT value is nominally 2 to 5 times higher (more conservative) than typical annual average total dust loading in non-arid regions (Yu 2001).
Soil Ingestion Rate	SOIL	g/y	18.3	Triangular	Range: 0 to 36.5	RESRAD Default. USEPA default value for adults engaged in non-contact intensive activities (50 mg/day) (Yu 2001; EPA 1997a).
A comprehensive list of the input parameters used in the execution of the RESRAD dose modeling code to evaluate the potential future radiation dose for the Naturalist Scenario is provided in the RESRAD output files (reports) in Appendix B for the subsurface soil source term and Appendix F for the surface soil source term.						

5.6 RECREATIONAL FISHER SCENARIO

5.6.1 Description of the Critical Group

The critical exposure group for the recreational fisher scenario is described by hypothetical subpopulation that frequently fishes recreationally on the site and consumes a considerable amount of fish harvested from surface waters impacted by residual radioactivity from the site. This fisher (as conservatively described) is likely to spend a large fraction of his available outdoor recreational time engaged in fishing and returns to the MDNR site each time rather than visiting other sites or roaming about the vast non-impacted Tobico Marsh State Game Area lands in search of fishing spots.

5.6.2 Pathways Included in the Recreational Fisher Scenario

Table 5-9 identifies the pathways that have been retained for the analysis and provides explanation for those pathways that were not retained.

Table 5-9 Evaluation of Pathways for the Recreational Fisher Scenario

Pathway	Retained	Remark
Direct Exposure	Yes	The source term found in the Site soils produces penetrating gamma radiation. Exposure from direct penetrating radiation is expected to be a significant contributor to the overall potential dose.
Particulate Inhalation	Yes	Allowance is made for soils containing radiological constituents of the source being liberated and suspended in the breathing air of the recreational fisher.
Radon	No	Radon is specifically excluded from consideration within the framework of the governing regulations. In addition, the source term found is not a significant producer of radon due to the relatively long half-life of the thorium isotopes found in the slag.
Plant Ingestion	No	Ingestion of plant foods addresses those plant foods grown in the radioactivity or irrigated with water containing radioactivity from on Site. Since recreational fishers are not expected to glean edible plant parts grown on site for food consumption, this pathway is incomplete.
Drinking Water	No	Surface water on site is unfit for consumption as drinking water. No on site sources of groundwater have been developed for drinking water.
Meat Ingestion	No	Recreational fishers are not expected to consume meat from game animals culled from the site.
Milk Ingestion	No	Milk ingestion pathway is incomplete since it is not credible to consider that recreational fishers would graze milk cows on this Site.
Aquatic Foods Ingestion	Yes	Recreational fishers are expected to spend time fishing and to consume fish caught in the surface water bodies surrounding the site.

Direct Ingestion	Yes	Fishers on the site may ingest relatively small amounts of soil through incidental oral contact with their hands.

5.6.3 Description of the Parameters Used in the Analysis

The recreational fisher scenario involves relatively conservative exposure factors attributable to members of the critical group, fishing enthusiasts, who may spend a considerable amount of time fishing and whose annual diet of aquatic foods is composed of a large fraction of fish caught while fishing on adjoining ponds/streams to the site. Key parameters used to define the recreational fisher exposure scenario are presented in Table 5-10 along with specific remarks explaining the values' selection. Table 5-10 contains only the key parameters describing the fisher's exposure and behavioral patterns (e.g., exposure time, inhalation rate, etc.) as all of the other site parameters—those describing the site in general, its weather, the geotechnical or physical abstraction, and the source term itself—are unchanged from those identified for the recreational hunter and presented in Table 5-5 and Table 5-6.

Table 5-10 Key Parameters—Recreational Fisher Scenario

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Receptor Exposure Factors						
Exposure Frequency (Total)	EF	Days per year	25	EF and ET are not input parameters used by RESRAD. They are presented here to disclose the calculation used to arrive at the parameters RESRAD uses to account for exposure frequency, FIND & FOTD.		Assumes 25 days per year spent fishing specifically on the Tobico Site.
Exposure Time	ET	Hours per Day	10			Conservatively assumes that each day spent fishing on site is 10-hours long.
Indoor Time Fraction	FIND	Unitless, 0 to 1	0	Point estimate		The fraction of a total year (8760 hr) that is spent indoors on Site. Assumes that all exposures occur outdoors. There are no habitable structures on the site.
Outdoor Time Fraction	FOTD	Unitless, 0 to 1	0.0285	Triangular	Range: 0 to 0.057	The fraction of a total year (8760 hr) that is spent outdoors on Site. Equals 250 hrs outdoors on Site divided by 8760 hours. The probabilistic distribution ranges to twice the CT value (500 hrs per year spent fishing on the site).
Inhalation Rate	INHALR	m^3/yr	8400	Triangular	Range: 4380 to 13100	RESRAD Default. Inhalation rate based on geometric mean rate for short-term exposure to adult males (Yu 2001, EPA 1997a).
Contaminated Fraction of Aquatic Foods	FR9	Unitless, 0 to 1	0.39	Triangular	Range: 0 to 1.0	RESRAD Default. The fraction of the annual aquatic foods diet that is obtained from surface waters in the vicinity of the site. The number is conservative in that it includes edible shell fish which are not part of the local aquatic habitat and because it requires that up to 100% of the aquatic foods diet is harvested from surface water bodies immediately impacted by the site (Yu 2001, EPA 1997b).

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Mass Loading for Inhalation	MLINH	g/m^3	0.00003	Continuous Linear	0.000000: 0.0000 0.000008: 0.0151 0.000016: 0.1365 0.000030: 0.8119 0.000040: 0.9495 0.000060: 0.9937 0.000076: 0.9983 0.000100: 1.0000	RESRAD Default. Mass loading in air describes the airborne dust loading conditions on the Site. The RESRAD default CT value is nominally 2 to 5 times higher (more conservative) than typical annual average total dust loading in non-arid regions (Yu 2001).
Soil Ingestion Rate	SOIL	g/y	18.3	Triangular	Range: 0 to 36.5	RESRAD Default. USEPA default value for adults engaged in non-contact intensive activities (50 mg/day) (Yu 2001, EPA 1997a).
A comprehensive list of the input parameters used in the execution of the RESRAD dose modeling code to evaluate the potential future radiation dose for the Recreational Fisher Scenario is provided in the RESRAD output files (reports) in Appendix C for the subsurface soil source term and Appendix G for the surface soil source term.						

5.7 COMPOSITE RECREATIONAL USER SCENARIO

In order to address the rather remote possibility that a single receptor might engage to a significant extent in all three forms of recreational land use and involving consumption of some meat, fish, and plant foods derived from the site, MDNR has also considered a "composite" recreational user scenario.

5.7.1 Description of the Critical Group

The critical exposure group for the composite recreational user scenario is described by the hypothetical subpopulation that frequently visits the site to hunt, fish, and observe the natural surroundings at the site. The composite recreational user is assumed to consume a considerable amount of game meat, fish, and edible plant foods harvested from the site. This user (as conservatively described) is likely to spend a large fraction of his available outdoor recreational time engaged in hunting, fishing, and nature viewing activities and returns to the MDNR site each time rather than visiting other sites or roaming about the vast non-impacted Tobico Marsh State Game Area lands in search of other spots from which to enjoy these activities.

5.7.2 Pathways Included in the Composite Recreational User Scenario

Table 5-11 identifies the pathways that have been retained for the analysis and provides explanation for those pathways that were not retained.

Table 5-11 Evaluation of Pathways for the Composite Recreational User Scenario

Pathway	Retained	Remark
Direct Exposure	Yes	The source term found in the Site soils produces penetrating gamma radiation. Exposure from direct penetrating radiation is expected to be a significant contributor to the overall potential dose.
Particulate Inhalation	Yes	Allowance is made for soils containing radiological constituents of the source being liberated and suspended in the breathing air of the composite recreational user.
Radon	No	Radon is specifically excluded from consideration within the framework of the governing regulations. In addition, the source term found is not a significant producer of radon due to the relatively long half-life of the thorium isotopes found in the slag.
Plant Ingestion	Yes	Ingestion of plant foods addresses those plant foods grown in the radioactivity or irrigated with water containing radioactivity from on Site. Visitors to the site may conceivably consume edible plant parts grown on site.
Drinking Water	No	Surface water on site is unfit for consumption as drinking water. No on site sources of groundwater have been developed for drinking water.

Meat Ingestion	Yes	Composite recreational users are assumed to engage in hunting and are expected to consume meat from animals culled from the site.
Milk Ingestion	No	Milk ingestion pathway is incomplete since it is not credible to consider that milk cows would graze on this Site.
Aquatic Foods Ingestion	Yes	Composite recreational users are assumed to engage in fishing and are expected to consume fish caught in the surface water bodies surrounding the site.
Direct Ingestion	Yes	Composite recreational users on the site may ingest relatively small amounts of soil through incidental oral contact with their hands.

5.7.3 Description of the Parameters Used in the Analysis

The composite recreational user scenario involves very conservative exposure factors attributable to members of the critical group, "composite" recreational land users, who hypothetically spend a considerable amount of time hunting, fishing, and observing the natural surroundings at the site and who, while visiting, consume plant food gleaned from wild plants growing on the site. They are also assumed to consume game meat and fish harvested from or adjoining the site. Key parameters used to define the composite recreational user scenario are presented in Table 5-12 below along with specific remarks explaining the values' selection. Table 5-12 contains only the key parameters describing the composite recreational land user's exposure and behavioral patterns (e.g., exposure time, inhalation rate, etc.) as all of the other site parameters—those describing the site in general, its weather, the geotechnical or physical abstraction, and the source term itself—are unchanged from those identified for the recreational hunter presented in Table 5-5 and Table 5-6 above.

Table 5-12 Key Parameters—Composite Recreational User Scenario

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	**Code**	**Unit**		**Distribution**	**Range & Fit**	
Receptor Exposure Factors						
Exposure Frequency (Total)	EF	Days per year	25	EF and ET are not input parameters used by RESRAD. They are presented here to disclose the calculation used to arrive at the parameters RESRAD uses to account for exposure frequency, FIND & FOTD.		Assumes 25 days per year spent viewing nature specifically on the Tobico Site.
Exposure Time	ET	Hours per Day	10			Conservatively assumes that each day spent on site is 10-hours long.
Indoor Time Fraction	FIND	Unitless, 0 to 1	0	Point estimate		The fraction of a total year (8760 hr) that is spent indoors on Site. Assumes that all exposures occur outdoors. There are no habitable structures on the site.
Outdoor Time Fraction	FOTD	Unitless, 0 to 1	0.0285	Triangular	Range: 0 to 0.057	The fraction of a total year (8760 hr) that is spent outdoors on Site. Equals 250 hrs outdoors on Site divided by 8760 hours. The probabilistic distribution ranges to twice the CT value (500 hrs per year spent viewing nature on the site).
Inhalation Rate	INHALR	m^3/yr	8400	Triangular	Range: 4380 to 13100	RESRAD Default. Inhalation rate based on geometric mean rate for short-term exposure to adult males (EPA 1997a, Yu 2001).
Contaminated Fraction of Plant Food	FPLANT	Unitless, 0 to 1	0.0285	Triangular	Range: 0 to 0.057	The fraction of the annual plant foods diet that is obtained from edible, natural succession vegetation grown on the site. Equals the fraction used to describe the naturalist receptor's diet.
Contaminated Fraction of Meat	FMEAT	Unitless, 0 to 1	0.3	Triangular	Range: 0 to 0.5	The fraction of the annual meat diet that is obtained from game harvested from off the site. Equals the fraction used to describe the hunter receptor's diet (EPA 1997b).
Contaminated Fraction of Aquatic Foods	FR9	Unitless, 0 to 1	0.39	Triangular	Range: 0 to 1.0	RESRAD Default. The fraction of the annual aquatic foods diet that is obtained from surface waters in the vicinity of the site. Equals the fraction used to describe the fisher receptor's diet (EPA 1997b, Yu 2001).

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Mass Loading for Inhalation	MLINH	g/m^3	0.00003	Continuous Linear	0.000000: 0.0000 0.000008: 0.0151 0.000016: 0.1365 0.000030: 0.8119 0.000040: 0.9495 0.000060: 0.9937 0.000076: 0.9983 0.000100: 1.0000	RESRAD Default. Mass loading in air describes the airborne dust loading conditions on the Site. The RESRAD default CT value is nominally 2 to 5 times higher (more conservative) than typical annual average total dust loading in non-arid regions (Yu 2001).
Soil Ingestion Rate	SOIL	g/y	18.3	Triangular	Range: 0 to 36.5	RESRAD Default. USEPA default value for adults engaged in non-contact intensive activities (50 mg/day) (Yu 2001, EPA, 1997a).
A comprehensive list of the input parameters used in the execution of the RESRAD dose modeling code to evaluate the potential future radiation dose for the Composite Recreational User Scenario is provided in the RESRAD output files (reports) in Appendix D for the subsurface soil source term and in Appendix H for the surface soil source term.						

5.8 UNCERTAINTY ANALYSIS

5.8.1 Managing Uncertainty

There is an inherent uncertainty in any projection of a future condition. Thus, scientists, statisticians, and even weather forecasters have developed tools to help them model or project a future condition and to understand the uncertainty associated with such projections.

In the past, dose assessments in support of USNRC decommissioning requirements relied primarily on the use of deterministic (single point estimate) analyses. The deterministic approach has the advantage of being simple to implement and easy to communicate to a non-specialist audience. However, it has a significant drawback in not allowing consideration of the combined effects of uncertainty in input parameters. It also fails to provide information on the degree of uncertainty in the model results, which would be helpful to the decision maker. To overcome these weaknesses and to ensure that a deterministic analysis had a high probability of erring conservatively, dose/risk assessors often relied on the use of worst-case (grossly conservative) estimates of each parameter of the model, typically leading to overly conservative evaluations and unnecessarily restrictive DCGLs.

The alternative to the deterministic approach is the probabilistic approach in which the overall uncertainty in the assessment is evaluated to arrive at a better estimate of the correspondence between residual radioactive concentration and the extent of incremental dose to an exposed receptor. Uncertainty analysis imparts more information to the decision maker than deterministic analysis. It characterizes a range of potential doses and the likelihood that a particular dose would be exceeded.

Regardless of the method, uncertainty is inherent in all dose and risk assessment calculations and should be considered in determining whether a selected DCGL concentration will satisfy the regulatory decision-making criteria. In general, there are three primary sources of uncertainty in a dose/risk assessment (Bonano et.al., 1988, and Kozak et al., 1991):

- Uncertainty in the models;
- Uncertainty in scenarios; and
- Uncertainty in the parameters.

Models are simplifications of reality and, in general, several alternative models may be consistent with available data. Computer modeling codes have permitted the analyst to increasingly refine the models they use because the computer is handling the complex calculations that result. The RESRAD dose modeling code used in this evaluation has been developed and maintained using a stringent version control process. The models (or components of them) are tested for mathematical correctness, verified, and benchmarked against comparable models, when available. Modeling in and of itself implies a degree of uncertainty in that direct measurements or standards are typically not available to compare to modeled results. It is in such cases that risk managers resort to models. Perhaps the most important factor in building confidence in the predictions of a model is selecting the model that most closely approximates the scenario to be evaluated.

Uncertainty in scenarios is the result of our lack of absolute knowledge about the future uses of the Site. It is important to recognize that the outlook evaluation time criterion (1,000 years) is not intended to predict future scenarios for the next 1,000 years, but to evaluate the continued protectiveness of a given DCGL for 1,000 years into the future given the reasonable and plausible future uses of the Site in today's social and economic conditions.

Parameter uncertainty results from incomplete knowledge of the coefficients that describe the model. However, with the selection of a suitable model for the Site conditions and scenarios to be considered, and configuring the model with realistic and most probable input parameters, the risk-manager may be reasonably confident in the model's predictions.

The current regulatory philosophy is to evaluate the uncertainty in an estimate along with the severity of consequence and probability of exceeding a deterministic regulatory limit. Such a decision method is termed "risk-informed decision making." The advent of powerful personal computers and increasingly capable software tools coupled with increased knowledge of key physical, behavioral, and metabolic parameters used to make dose/risk assessments, have brought probabilistic analysis to the state of the art. While not all regulating agencies currently expect that assessments will employ the probabilistic approach, with a quantitative assessment of the associated uncertainties, the USNRC has adopted a risk-informed approach to regulatory decision making, suggesting that an assessment of uncertainty be included in dose assessments (NRC 2000). The USNRC's Probabilistic Risk Assessment (PRA) Policy Statement (NRC 1995) states, in part, "The use of PRA technology should be increased in all regulatory matters to the extent supported by the state of the art in PRA methods and data, and in a manner that complements the USNRC's deterministic approach…."

Even with the use of probabilistic analyses, it should be recognized that not all sources of uncertainty could be, or need to be, considered in a dose assessment. The primary emphasis in uncertainty analysis is to identify the important assumptions and parameter values that, when altered, could change the decision.

Sensitivity analysis performed in conjunction with the uncertainty analysis is used to identify parameters and assumptions that have the largest effect on the overall result and provides a tool for understanding and explaining the influence of these key assumptions and parameter values on the variability of the estimated dose.

5.8.2 Addressing Sources of Uncertainty

As mentioned above, an important issue in uncertainty and sensitivity analysis is that not all sources of uncertainty can be easily quantified. Of the three primary sources of uncertainty in dose assessment analyses, parameter uncertainty analysis is most mature and will be dealt with quantitatively in this section.

However, mathematical approaches for quantifying the uncertainty in the site conceptual models and future use scenarios are not well developed. For example, it is difficult to predict with absolute certainty the characteristics of a future society. For these reasons, no attempt to formally quantify model or scenario uncertainty is made. To confront these uncertainties an acceptably complete suite of scenarios capturing the plausible range of future uses for this site, given the nature and site-specific impediments to future land development, has been developed and is considered in the assessment (Flavelle 1992). In addition, conceptual site models have been designed and selected to represent the existing features at the Site and to conservatively represent the conditions that might be encountered in each scenario. A notable example of this strategy is seen in the decision to depict receptors exposed in the recreational land use scenarios who obtain substantially large fractions of their diet (meat, fish, plant) from potentially impacted onsite sources, even though the site has a very low ability to sustain sufficient quantities of meat, fish, and plant foods required to match the intake assumed in the various scenarios.

In reality, the uncertainties in the conceptual site model and the scenario selections are captured, to a certain extent, in the parameter uncertainty analysis.

5.8.3 Method of Addressing Uncertainty

MDNR has selected the most current version of the RESRAD dose modeling code (version 6.21, September 2002) to evaluate uncertainty in accordance with USNRC guidance (NRC 2000). It contains a probabilistic module that is used to assess the uncertainty in the relationship between a concentration of radioactivity in soil and the dose it might produce. It uses an enhanced random sampling algorithm called Latin Hypercube sampling in which input parameter values are selected randomly from probability distribution functions (PDF). The uncertainty module in the code permits the analyst to define the PDF for each variable of interest by selecting the distribution and its parameters, and to identify the parameter as either independent or correlated to other input variables.

The following describes the process used to evaluate uncertainty:

1. Each scenario was evaluated using the deterministic module to identify a concentration in soil corresponding to the deterministic regulatory limits. Additionally, coarse scale sensitivity analysis was performed to zero in on the parameters that had the greatest potential to impact the dose.
2. Pathways of interest were identified through preliminary runs of the deterministic module in the code for all the scenarios. These identified the scenario specific pathways that most significantly contributed to dose. The direct exposure pathway, or "ground" pathway was consistently the dominant pathway for exposure to the source term, and by a significant margin.
3. Where site-specific knowledge was lacking, where the dose response was not sensitive to variability in a given parameter, or where the default parameter distributions were reasonably representative of site conditions or conditions being

portrayed in the exposure scenario, the default was used. Where no default distribution is recommended or where discreet knowledge of site-specific conditions exists, an appropriate distribution considering the degree of knowledge of site-specific conditions was selected.

4. The Latin-Hypercube sampling algorithm (a variant of the Monte Carlo sampling technique which has an advantage in that it forces the sampling to occur over the entire range of possible values in the PDF rather than rely on pure random sampling) was set to obtain 1,500 samples (300 samples, repeated five times).

5.8.4 Parameter Distributions

Parameters to which probability density functions were assigned in order to evaluate their impact on uncertainty are presented in this section. They are organized such that the receptor exposure parameters are presented first, followed by general site and meteorological parameters, and then the geotechnical parameters describing the various soil layers starting with the cover and concluding with the saturated layer.

5.8.4.1 Outdoor Time Fraction (FOTD)

RESRAD uses fractions of a whole year spent on site to calculate annual dose to a receptor. The total fraction of a year spent on site is divided between two parameters: indoor time fraction (FIND) and outdoor time fraction (FOTD). Fractions of time spent on site are wholly dependent upon the scenario under consideration. Each of the four scenarios evaluated in the derivation of the site-specific soil DCGL assumes that the indoor time fraction is zero, denoting that all exposure on site occurs outdoors. The value used to describe the on site, outdoor time fraction for each of the recreational use scenarios is derived from conservative assumptions attributed to members of the critical exposure group and designed to be conservative for the general population of potentially exposed individuals.

Sensitivity analysis indicates that total annual dose is sensitive to variability in the FOTD parameter as the penetrating gamma (ground) exposure pathway dominates and is strongly dependent on exposure duration. In setting up the uncertainty analysis, the FOTD parameter is represented with a triangular distribution. Figure 5–9 graphically illustrates the distribution from which values of outdoor time fractions are sampled.

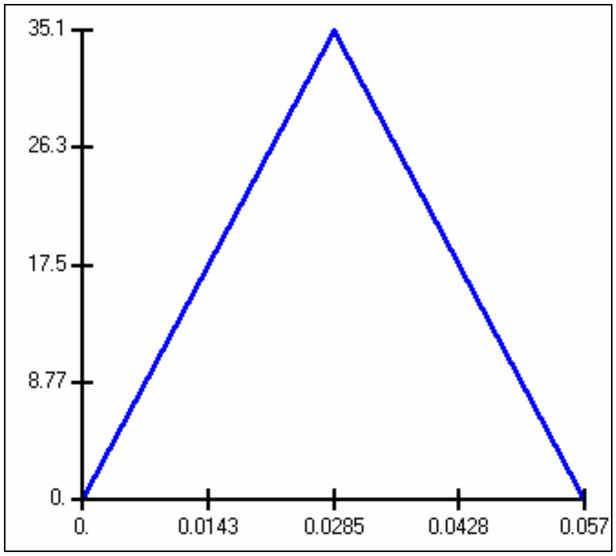

Figure 5–9 Outdoor Time Fraction—All Scenarios (unitless)

5.8.4.2 Inhalation Rate

Inhalation rate (INHALR) is the air intake in m^3 per year. It is used to calculate the dose from the inhalation pathway. The parameter represents the annual average breathing rate for a receptor from the critical exposure group subpopulation performing tasks under evaluation in a given scenario.

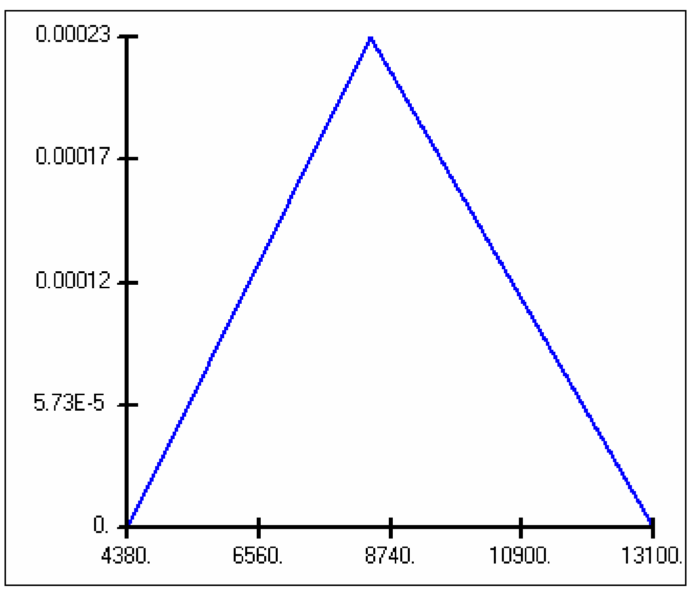

Figure 5–10 Inhalation Rate—Adults, Outdoor Activities (m^3/y)

Population normalized inhalation rates vary depending upon the tasks that are being performed. For the recreational land user, the inhalation rate used is the RESRAD default, which is derived from International Commission on Radiological Protection (ICRP) and EPA recommendations for adults engaged in short-term (episodic) exposure scenarios (ICRP 1981, EPA 1985, EPA 1997a). Sensitivity analysis shows that the total annual dose is not sensitive to this parameter, because the inhalation pathway is not a significant contributor to total annual dose. Inhalation rate is represented with a triangular distribution (the RESRAD default). Figure 5–10 graphically illustrates the distribution from which values of inhalation rate are sampled.

5.8.4.3 Contaminated Fraction of Meat Diet

The meat ingestion pathway is unique to the hunter and "composite" recreational user scenarios. Evaluation of the potential dose from this pathway considers both the annual consumption of meat and poultry, DIET(4) (using the RESRAD default value of 63 kilograms per year), and the fraction of that annual meat diet that is potentially impacted with residual radioactivity from the site (FMEAT).

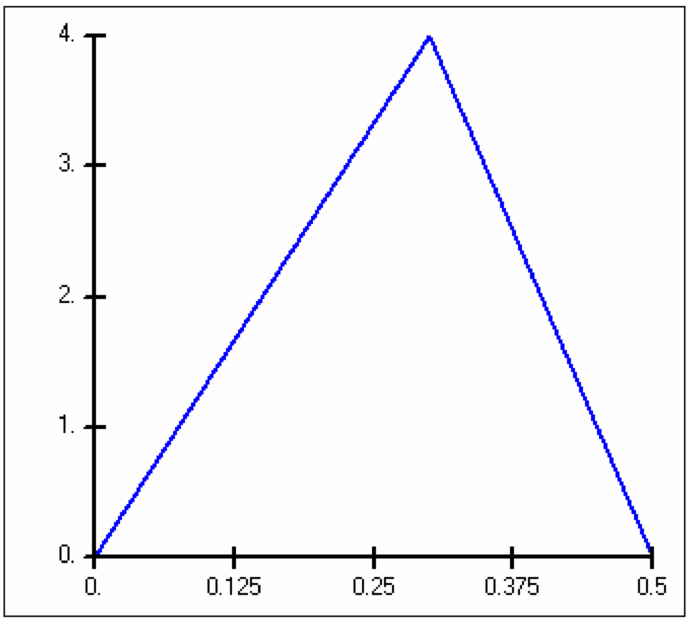

Figure 5–11 Contaminated Fraction of Meat (unitless)

A triangular distribution was selected to represent the range and variability in the fraction of the receptor's meat diet that might have been culled from among game animals that grazed on the site. The mode of the distribution (the most likely value) was selected based upon the typical dressed weight of a white-tail deer (~40 lbs., 19 kg), the most abundant game species in the area. The contaminated fraction is estimated to range between 0 (no game meat harvested) and 0.5 (half of the entire annual meat diet consumed is derived from game grazed on the Tobico site). The fraction modeled is conservative in that the size of the site is small relative to the grazing land required to support game habitat. Sensitivity analysis shows that the total annual dose is not sensitive to this parameter, because the meat ingestion pathway is not a significant contributor to total annual dose for either the surface soil or subsurface soil source terms. Figure 5–11 graphically illustrates the distribution from which values of the contaminated fraction of meat is sampled.

5.8.4.4 Contaminated Fraction of Aquatic Foods Diet

The aquatic foods pathway is unique to the fisher and "composite" recreational user scenarios. Evaluation of the potential dose from this pathway considers both the annual consumption of fish [DIET(5)] and "other aquatic foods," such as shellfish [DIET(6)] (using the RESRAD default values of 5.4 and 0.9 kilograms per year respectively), as well as the fraction of that annual aquatic foods diet that is potentially impacted with residual radioactivity from the site (FR9). A triangular distribution was selected to represent the range and variability in the fraction of the receptor's aquatic foods diet (fish) that might have been caught from surface waters impacted by residual radioactivity from the site. The RESRAD default distribution (triangular, with mode of 0.39 and a range of 0 to 1.0) was selected. The fraction modeled is conservative in that it assumes that the entire annual aquatic foods diet is derived from freshwater fish consumption only. In reality, a relative large fraction of the annual aquatic foods diet for a typical receptor is made up of a large portion of seafood and shellfish species not available at the site. Figure 5–12 graphically illustrates the distribution from which values of the contaminated fraction of aquatic foods is sampled.

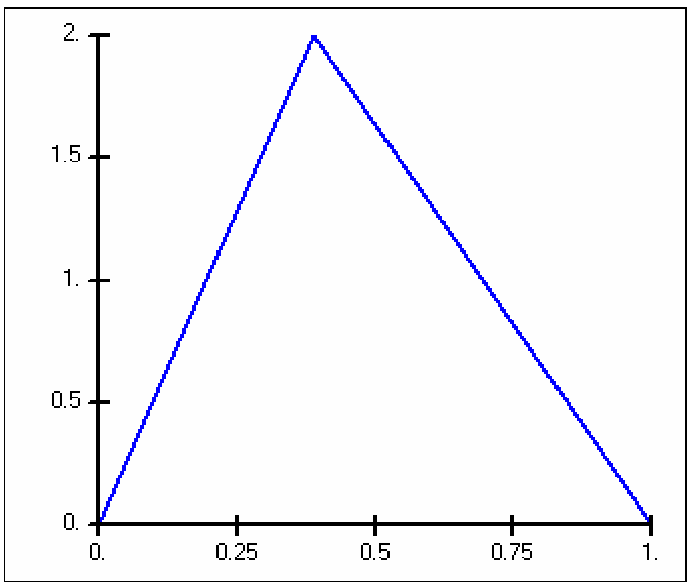

Figure 5–12 Contaminated Fraction of Aquatic Foods (unitless)

Sensitivity analysis shows that neither the aquatic foods ingestion pathway, nor the total annual dose is sensitive to this parameter because the isotopes of concern at the Site are relatively insoluble and immobile in soil.

5.8.4.5 Contaminated Fraction of Plant Food Diet

The plant foods pathway is unique to the naturalist and "composite" recreational user scenarios. Evaluation of the potential dose from this pathway considers both the annual consumption of plant foods, DIET(1) and DIET(2) (using the RESRAD default values of 160 and 14 kilograms per year respectively), as well as the fraction of that annual plant foods diet that is potentially impacted with residual radioactivity from the site (FPLANT).

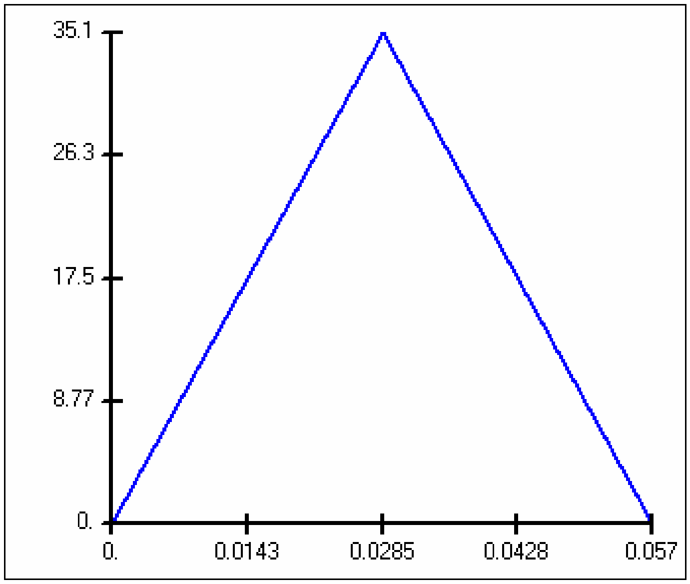

Figure 5–13 Contaminated Fraction of Plant Food (unitless)

A triangular distribution was selected to represent the range and variability in the fraction of the receptor's annual plant food diet that is derived from edible plants, sustained by natural succession, and which grew on and in the clay cover of the cell. RESRAD does not offer a default distribution for the FPLANT parameter as it is highly dependent upon the scenario and the ability of the site to sustain edible plant production. For this evaluation, a triangular distribution was used to represent the fraction of the receptor's plant food diet that might come from the site. The range and mode are chosen to correspond with the probability density function describing the fraction of time on site (FOTD) with the idea that plant food consumption would occur as a result of gleaning edible, natural succession plants while on site observing nature. Logically, then, the mode of the triangular distribution is 0.0285 with a range of 0 to 0.057, allowing for 0 to 5.7% of the receptor's annual plant food diet to be derived from plants grown on the site. The fraction modeled is conservative in that the cover is designed to support plants with very shallow root depths such as species of native grasses (for erosion control) and is not conducive to the sustenance of plant species that might serve as a human food source. Figure 5–13 graphically illustrates the distribution from which values of the contaminated fraction of plant food is sampled.

Sensitivity analysis shows that neither the plant foods ingestion pathway, nor the total annual dose are sensitive to this parameter because the sustainable root depth is shallow and the thickness of the engineered clay cover layer effectively isolates plants from contact with the subsurface soil residual radioactivity. The surface soil source term analysis is somewhat more sensitive to this parameter because the plant roots are assumed to be in intimate contact with residual radioactivity. Still, the total annual dose is dominated by the external penetrating gamma radiation pathway.

5.8.4.6 Mass Loading for Inhalation

Mass loading for inhalation (MLINH) is the soil/air concentration ratio. It is used to calculate the dose from the particle inhalation pathway. The parameter represents the dust (mass) loading on site conservatively assuming that all airborne dust is generated on Site and is radioactive. Other parameters, derived by the RESRAD code and based upon the site-specific parameters input, are used to modify this assumption, as appropriate. Mass loading does vary from season to season and depends upon the activities that are being performed at the Site. The RESRAD default continuous liner distribution and fit with a CT value of 0.00003 g/m3 (30 µg/m3) and ranging up to 100 µg/m3 are used for each of the recreational visitor scenarios evaluated. The use of the RESRAD default is conservative as PM10 monitoring in the Midland–Bay City–Saginaw area indicates annual average dust loading to be approximately 10 µg/m3 (MDEQ 2000), one third those used in the default.

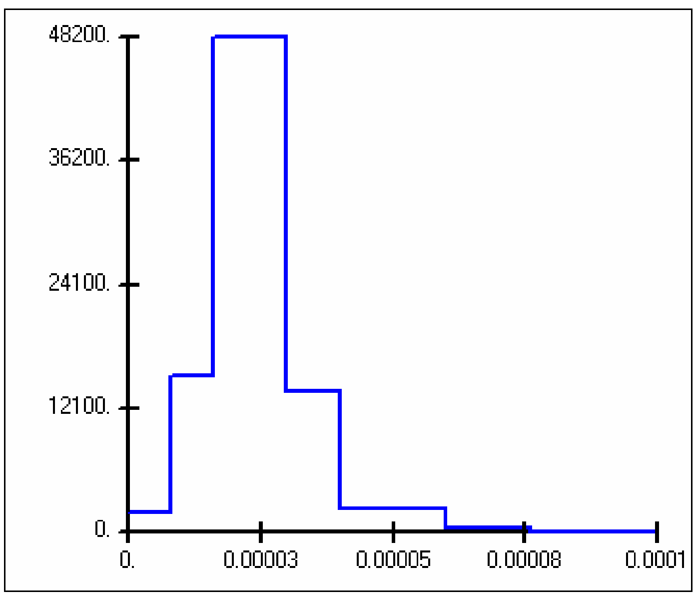

Figure 5–14 Mass Loading for Inhalation (g/m^3)

Sensitivity analysis shows that the inhalation pathway and total annual dose are insensitive to this parameter because the radioactivity is effectively isolated from the receptor by the in-place cover material. Figure 5–14 graphically illustrates the distribution from which values of mass loading in air are sampled.

5.8.4.7 Soil Ingestion Rate

RESRAD uses the annual average soil ingestion rate (SOIL) to calculate the dose from the direct soil ingestion pathway. The soil ingestion rate used in deriving the soil DCGL for the site is represented by a triangular distribution centered at 18.3 g/y (50 mg/d) and ranging from 0 to 36.5 g/y (0 to 100 mg/d), the RESRAD default.

Sensitivity analysis again shows that neither the soil ingestion pathway nor the annual effective dose equivalent is sensitive to this parameter because the radioactivity is effectively isolated from the receptor by the in place cover material. Figure 5–15 graphically illustrates the distribution from which values of soil ingestion rate (SOIL) are sampled.

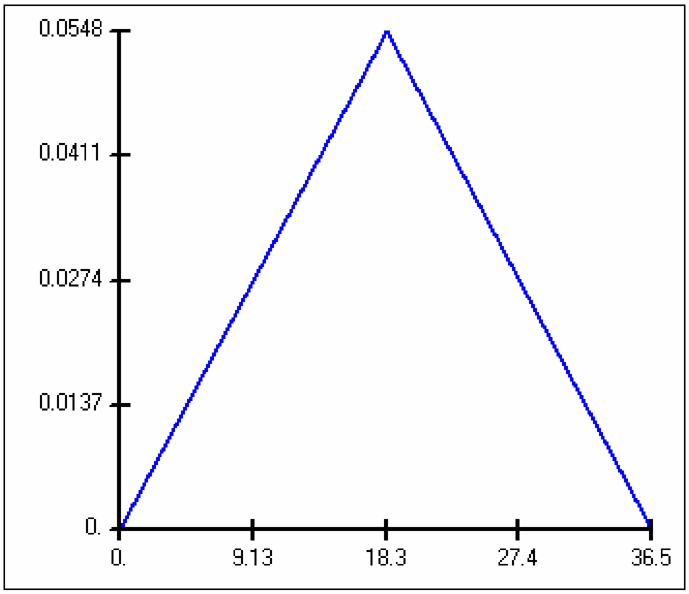

Figure 5–15 Soil Ingestion Rate (g/y)

5.8.4.8 Evapotranspiration Coefficient

The evapotranspiration coefficient (EVAPTR) is the fraction of total precipitation that is released back to the atmosphere via plant "respiration." Evapotranspiration varies with geographic region and to some extent with soil type. Evapotranspiration rates in the Midland/Bay City/Saginaw (MBS), Michigan region are estimated to be approximately 24 inches per year (Yu 1993), corresponding to a most likely evapotranspiration coefficient of approximately 0.85 (average annual precipitation in the region is 28.5 inches, (National Climatological Data Center, NOAA)).

The evapotranspiration coefficient is conservatively represented with a uniform distribution ranging between 0.5 and 0.75 (the RESRAD default). Sensitivity analysis showed that annual dose is insensitive to values of evapotranspiration coefficient over the entire RESRAD default range. Figure 5–16 graphically illustrates the distribution from which values of evapotranspiration coefficient are sampled.

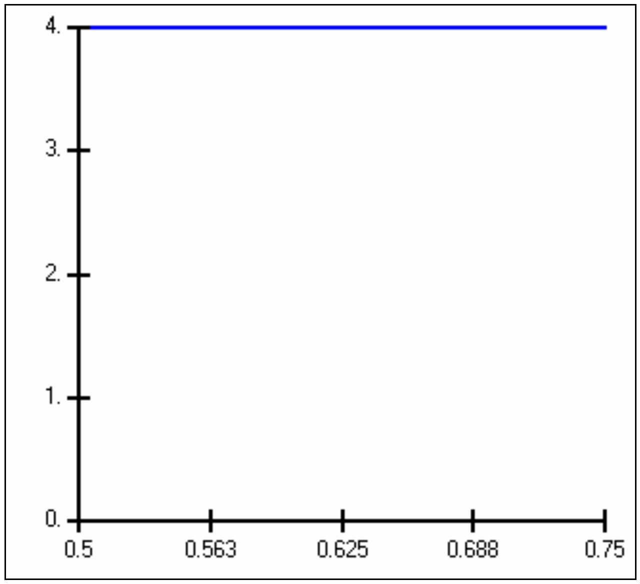

Figure 5–16 Evapotranspiration Coefficient (dimensionless)

5.8.4.9 Wind Speed

Average annual wind speed is used to calculate the dose from the inhalation pathway. The wind speed is used to transport airborne dust generated on Site in a standard air dispersion model. Through the transport calculations, the radioactive fraction of the total dust loading in air is derived. The fraction is then used to calculate particle inhalation intake. While wind speeds do vary from day-to-day and season-to-season, the annual average wind speed is reasonably steadfast. Sensitivity analysis shows that the inhalation pathway is insensitive to this parameter because, the residual radioactivity is effectively isolated by the covering layer such that radioactive particle suspension is minor. As a result, the inhalation pathway is not a significant contributor to total annual dose. Wind speed is represented with the RESRAD default, bounded lognormal-N distribution. The default data fit to the distribution was also used as the site-specific wind speed data is closely approximated by the RESRAD default. For example, the site-specific annual mean wind speed is reported to be 4.18 m/sec (National Climatological Data Center, NOAA), a near perfect match to the 4.24 m/sec value described by the RESRAD default. Figure 5–17 graphically illustrates the distribution from which values of annual average wind are sampled.

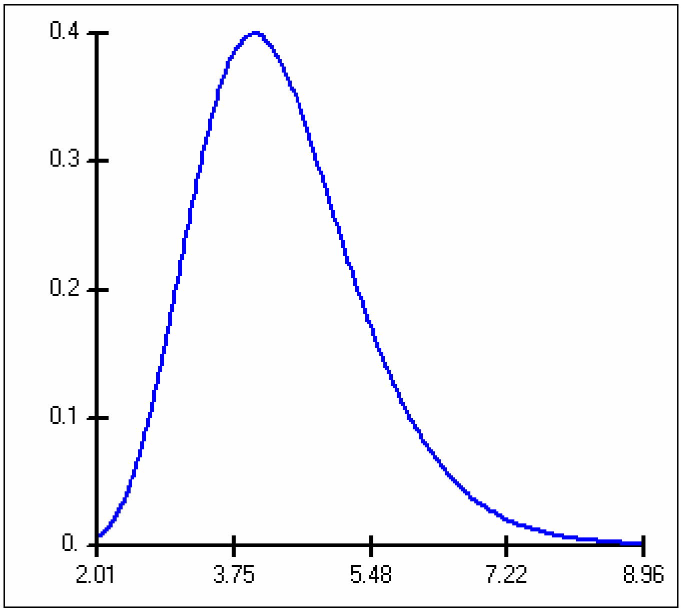

Figure 5–17 Average Annual Wind Speed (m/sec)

5.8.4.10 Runoff Coefficient

The runoff coefficient is one of a number of parameters used to calculate radionuclide leaching from the contaminated zone. It is the fraction of precipitation that does not penetrate the top soil layer. The runoff coefficient (RUNOFF) varies with topography, amount of pavement, precipitation patterns in the region, and soil type. Runoff coefficient is represented with the RESRAD default parameter distribution, a uniform distribution ranging between 0.1 and 0.8 (10% to 80% of precipitation runs off without penetrating the surface). Considering the mounded topography of the site and the presence of the engineered clay soil cover over the cell, the true range is likely to be much narrower and near the maximum value (80%) considered in the probability distribution. Sensitivity analysis showed that annual dose is insensitive to values of runoff coefficient over the entire range of plausible values. Figure 5–18 graphically illustrates the distribution from which values of runoff coefficient are sampled.

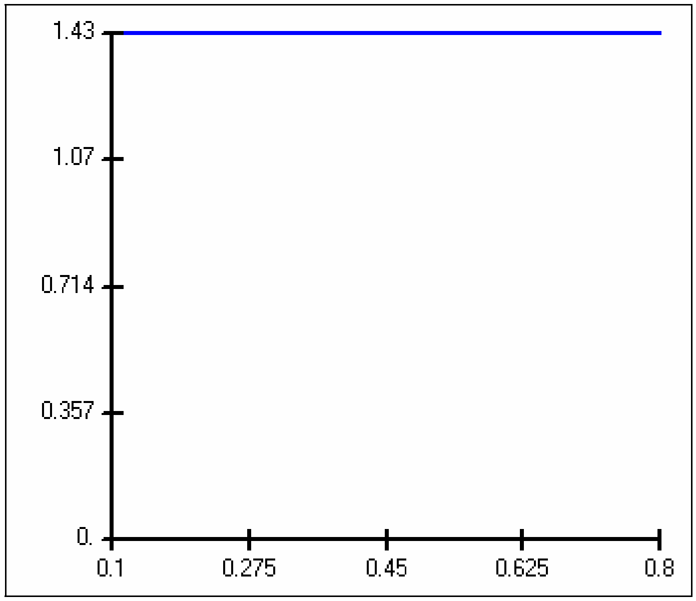

Figure 5–18 Runoff Coefficient (dimensionless)

5.8.4.11 Depth of Soil Mixing Layer

This parameter (DM) is used in calculating the depth factor for the dust inhalation and soil ingestion pathways and for foliar deposition for the ingestion pathways. The depth factor is the fraction of resuspendable soil particles at the ground surface that are contaminated, which is calculated by assuming that mixing of the soil will occur within a layer of thickness, DM, at the surface. The RESRAD default distribution (triangular) and range was used. Figure 5–19 graphically illustrates the distribution from which values of the depth of the soil mixing layer is sampled.

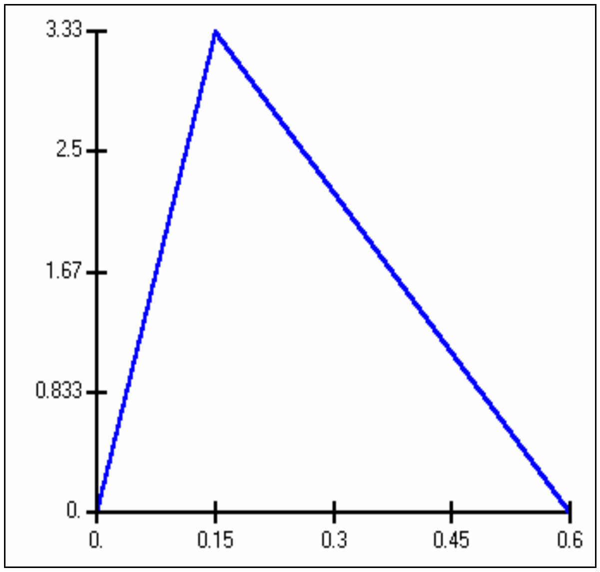

Figure 5–19 Depth of Soil Mixing Layer (m)

5.8.4.12 Cover Depth (Thickness)

When modeling the subsurface soil source term, the cover depth (thickness) is a key parameter in assessing the protectiveness of the chosen decommissioning alternative as it provides a barrier to potential physical contact with residual radioactivity in the slag materials located within the cell, and a substantial degree of gamma radiation attenuation for the penetrating gamma radiation exposure pathway, the dominant, or critical dose pathway. From geotechnical logging performed in support of the scoping and characterization surveys, the engineered clay cover is shown to be between 4 to 7 feet (1 and 2 meters) thick over the portion of the cap circumscribed by the slurry walls. It has a typical thickness of approximately 1.52 meters (5 ft). RESRAD does not suggest a default probability distribution for cover depth (COVER0) as it is highly dependant upon site-specific conditions and for many sites does not exist at all. Thus MDNR has conservatively chosen to represent this parameter with a triangular distribution ranging between 1 and 2 meters thick and with a most likely value of 1.52 meters (5 ft.). This representation is conservative in that the cover tends to be thicker near the center/middle of the cell, thinning as it extends beyond the slurry wall. Nor does it take credit for the attenuating effect of the thin (~6 inch thick) top soil layer placed over the cover in order to support natural succession vegetation as an erosion control mechanism. Sensitivity analysis reveals that the "cover penetrating gamma radiation dose" pathway, and as a result the total annual effective dose equivalent, is sensitive to this parameter. As an added measure of conservatism, owing to its potential impact on dose, the cover thickness was modeled with a potential range extending down to 1 meter (almost one foot thinner than the minimum thickness measured). Figure 5–20 graphically illustrates the distribution from which values of cover depth were sampled.

When modeling the surface soil source term, the engineered clay cover layer actually underlies the surface soil contaminated zone layer and is identified in the RESRAD model as "unsaturated layer #1". As a result, the same probabilistic parameter set used to represent the cover layer when modeling the subsurface soil source term, is used to describe the thickness of unsaturated layer #1 (H1) in the surface soil source term model.

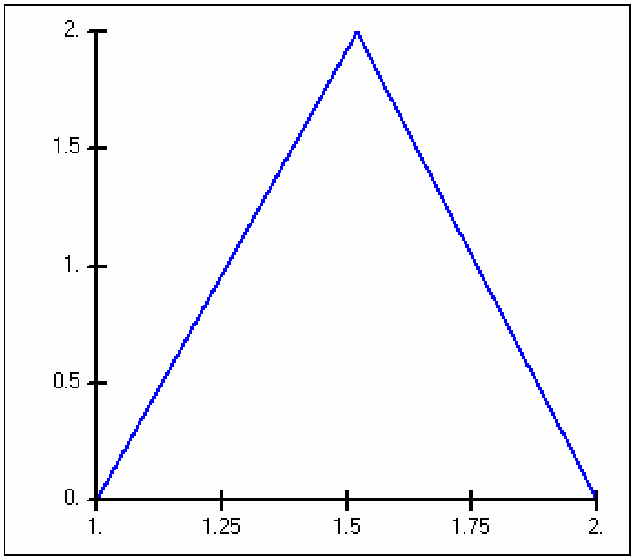

Figure 5–20 Engineered Clay Cover Thickness (m)

5.8.4.13 Cover Soil Density

The engineered cover is comprised of compacted clay soils. The soil density of native clay bearing soils at the site was measured to arrive at a site-specific estimate of the soil density of both the clay cover material and the undisturbed, clay-bearing, native glacial till layer underlying the Site. The measured soil density was found to be 1.97 g/cm^3, a number typical of high clay content soils. Sensitivity analysis showed that annual dose was insensitive to a wide range of soil densities. Since site-specific data was available for the density of the clay bearing materials at the site, these were used to describe the density of the cover soil layer. Cover soil density (DENSCV) was represented with a truncated normal distribution (the RESRAD default). The Mean was set equal to the measured density of 1.97 g/cm^3 and allowed to range between approximately 1.6 and 2.4 g/cm^3. Figure 5–21 graphically illustrates the distribution from which values of cover soil density were sampled.

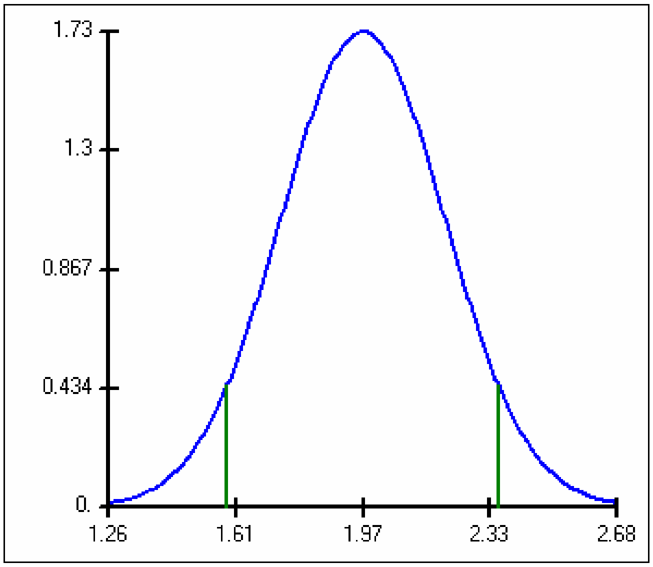

Figure 5–21 Cover Soil Density (g/cm³)

5.8.4.14 Surface Soil Erosion Rate

The Site has very little topographical variation because it is in the freshwater marsh (delta) formed by the outflow of the Saginaw River into the Saginaw Bay. The cell itself is slightly elevated in comparison to the immediately surrounding landscape by approximately 5 to 6 feet. Generally, the Site is characterized by relatively flat features (<2% grade).

The conceptual site model used to describe the conditions at the Site involves two different source terms: one, a hypothetical, thin, surface soil layer arising from the inadvertent cross-contamination of the surface during characterization sampling activities, and the other corresponding to the subsurface deposits of thoriated slag within the cell.

When modeling the surface soil source term, no cover layer is assumed. Thus, the surface soil is the surface soil contaminated zone and the surface soil erosion rate is captured in the RESRAD model as the contaminated zone erosion rate (VCZ). In recognition of the relatively flat topographic features present at the site, the general meteorological signature for the area, and the non-invasive nature of the future use scenarios all of which argue for lower than average soil erosion potentials, the contaminated zone erosion rate was conservatively modeled with a deterministic value (3×10^{-6} m/year) over 300 times slower than the RESRAD default value. Annual dose is not particularly sensitive to this parameter since the peak annual dose occurs in the first year after deposition, and decreases each year thereafter, regardless of the surface soil erosion rate used.

When modeling the subsurface soil source term, the conceptual site model includes a relatively thick clay soil cover layer, as has been described, engineered to resist the forces of erosion. In this case, the surface soil layer is the engineered clay cover layer and the surface soil erosion rate is captured in two important parameters within the RESRAD model. The cover layer erosion rate (VCV) is important because as cover erosion occurs, the underlying subsurface contaminated zone is exposed, increasing the potential for human exposure to radiation. Once the cover layer has been eroded, RESRAD further accounts for the effect of surface soil erosion through the contaminated zone erosion rate parameter (VCZ).

Sensitivity analysis shows that all pathways are sensitive to this parameter when represented with chronic and extreme erosion values such as those that might be observed in arid desert climates or where continual loosening of the surface soils occurs, such as might be expected for land used for agricultural purposes. In every scenario, the greatest annual dose occurs in the out years (year 1,000) when the cumulative effect of long-term soil erosion impacts the thickness of the cover layer and thus its attenuating affect. The cover erosion rate (VCV) has been conservatively estimated with a range of possible values to represent the likely and extreme erosion rates typical for conditions and activities expected at the site. Surface soil erosion is represented with a continuous logarithmic distribution (the RESRAD default) and ranging over approximately two decades from 8 x 10^{-7} to 6 x 10^{-5} m/year (Figure 5–22). The most probable range for a site in a humid climate, with a slope of approximately 2-percent, and natural succession vegetation extends from 8 x 10^{-7} to 3 x 10^{-6} m/year. Extreme surface soil erosion potential has been accounted for by estimating that there is as much as a 50% probability that the soil erosion rate will exceed this range, with estimates ranging to 6 x 10^{-5} m/year (the predicted maximum for sites used for permanent pasture) (Yu 1993).

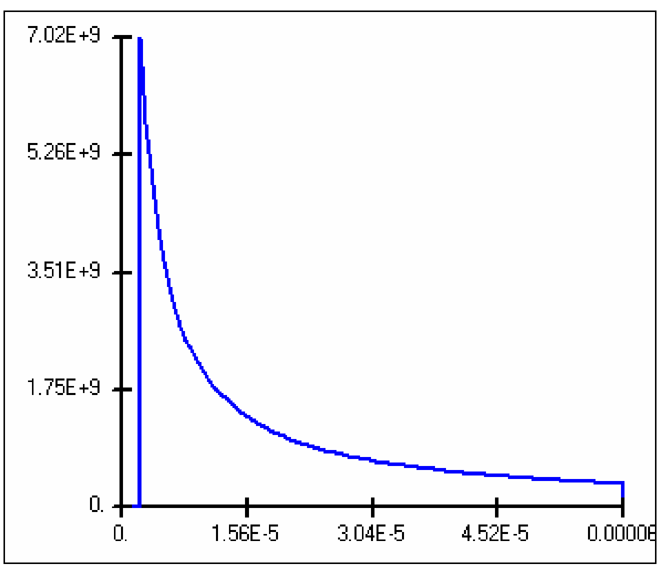

Figure 5–22 Soil Erosion Rate (m/y)

5.8.4.15 Depth of Plant Roots

The depth of plant roots is important only for the naturalists and composite recreational user scenarios (scenarios in which ingestion of plants grown on site is considered) as it is one of several parameters used to calculate dose from the intake of produce grown in soils having residual radioactivity. The depth of roots in these scenarios is effectively constrained by the fact that only a very thin layer of cover soil suitable for plant growth (≈6 inches) is actually in-place over the engineered clay cover layer. The engineered clay cover resists root penetration. This fact makes the root depth parameter more sensitive for the surface soil source term than for the subsurface soil source term, as a larger fraction of plant roots would be in direct contact with a surface soil contaminated zone.

When modeling the surface soil source term, sensitivity analysis shows that the plant ingestion pathway is somewhat sensitive to the value used to describe the root depth of edible plants, but only in the early years of the analysis before the cumulative effects of long-term surface soil erosion have reduced the source term thickness. While the plant ingestion pathway is somewhat sensitive to the root depth parameter, the dose from plant ingestion is still a minor fraction of the projected total annual dose.

When modeling the subsurface soil source term, sensitivity analysis again showed that the plant ingestion pathway was somewhat sensitive to root depth, but only in the out years of the analysis after the cumulative effects of long-term soil erosion have reduced the soil cover thickness to its projected minimum value. Even then, the plant ingestion dose is small when compared with the external penetrating radiation pathway.

Root Depth (DROOT) is represented in RESRAD with a lognormal-N distribution having a central tendency estimate of 0.15 m (6 inches) when modeling either the surface or subsurface soil source term. The majority of root depth values, as described in the distribution, range from 1 to 12 inches with the maximum root depth ranging to depths as deep as approximately 1 meter (40 inches). Figure 5–23 graphically illustrates the distribution from which values of root depth were sampled.

5.8.4.16 Weathering Removal Constant

The weathering removal constant is used to account for the natural removal of soil and dust that have been deposited on consumable plants. It is relevant only for the naturalist and composite recreational user scenarios (scenarios in which the consumption of plants is considered). Sensitivity analysis showed that annual dose was insensitive to the weathering removal constant (WLAM), thus the RESRAD default distribution (triangular) and range were used when modeling the subsurface soil source term. The RESRAD deterministic default (20/year) is used when modeling the surface soil source term. Figure 5–24 graphically illustrates the distribution from which values of the weathering removal constant parameter are sampled.

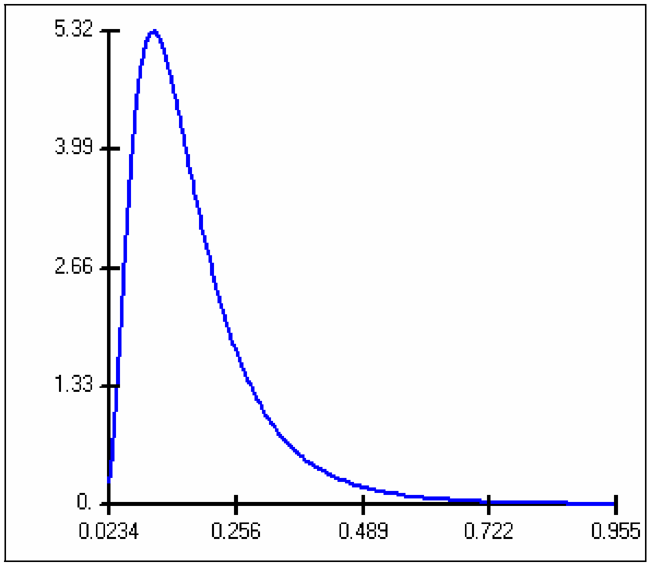

Figure 5–23 Depth of Plant Roots (meters)

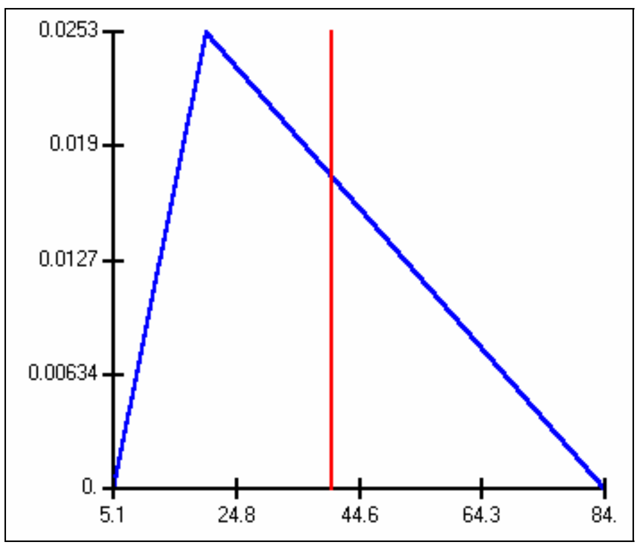

Figure 5–24 Weathering Removal Constant (dimensionless)

5.8.4.17 Area of Contaminated Zone

The area of the contaminated zone (AREA) describes the areal size, in square meters, of the region in which elevated concentrations of residual radioactivity are located. As described in Section 5.2.1.2, the areas describing the surface and subsurface soils source terms are related to one another but they are not necessarily equal to one another. Radiological sampling and measurement data from numerous radiological surveys performed at the site confirm that elevated subsurface radioactivity is confined to within the area circumscribed by the slurry walls of the cell. The Characterization Survey Report further delineates the region where elevated measurements occur, concluding that elevated activity is located principally along the trace of the former dirt road through the site and within an area of 791 m^2 (Cabrera 2001).

In defining the probability density function for the AREA parameter when modeling the subsurface soil source term, it was conservatively assumed that the contaminated zone area is no smaller than the 791 m^2 estimate derived from characterization survey data, but might be as large as the entire area circumscribed by the slurry wall, 5,725 m^2. RESRAD does not offer a default distribution for this parameter. A loguniform distribution ranging from the most likely value, 791 m^2, to a maximum value of 5,725 m^2 was selected to represent the area of the contaminated zone within the probabilistic module of RESRAD. Sensitivity analysis showed that annual dose was insensitive to the area of the subsurface soil contaminated zone. Figure 5–25 graphically illustrates the distribution from which values of the area of the contaminated zone parameter are sampled when modeling the subsurface soil source term.

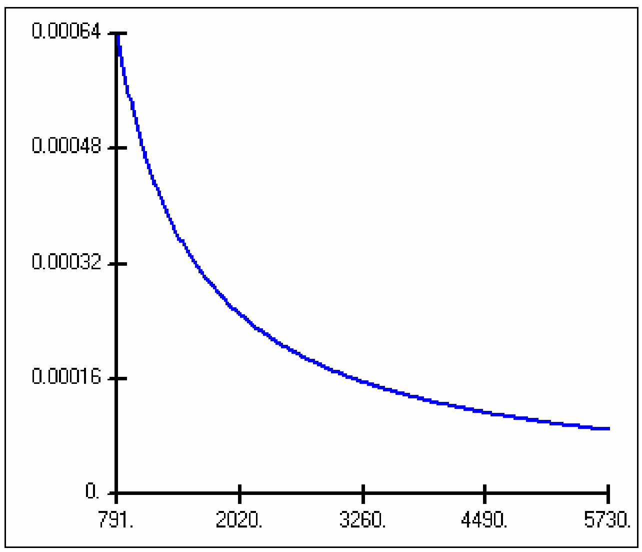

Figure 5–25 Area of Subsurface Soil Contaminated Zone (m^2)

When modeling the surface soil source term (see Section 5.2.1.2), the probability density function for the AREA parameter is represented with a triangular distribution having a mode of 57.3 m^2. The distribution allows for the likely possibility that the surface soil is not impacted by residual radioactivity from prior characterization activities as the lower bound is set at 0 m^2. It also conservatively considers the unlikely possibility that the contaminated zone area might be as large as the entire area circumscribed by the slurry wall, 5,725 m^2. Sensitivity analysis showed that annual dose was relatively sensitive to the area of the surface soil contaminated zone, but even three orders of magnitude variability in the area parameter resulted in less than 25 mrem difference in corresponding projected annual dose equivalent. Figure 5–26 graphically illustrates the distribution from which values of the area of the contaminated zone parameter are sampled when modeling the surface soil source term.

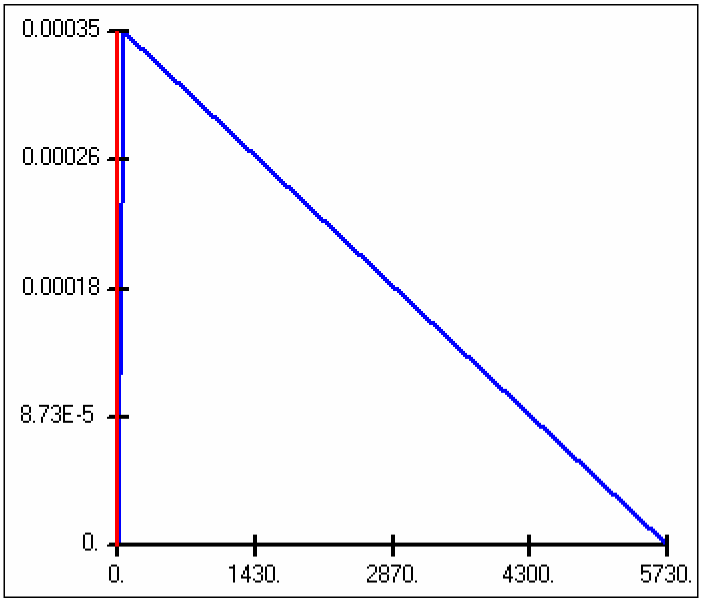

Figure 5–26 Area of Surface Soil Contaminated Zone (m^2)

5.8.4.18 Contaminated Zone Thickness

Thickness of the contaminated zone (THICK0) describes the depth profile of the residual radioactivity. Again, because of the two source terms considered, two contaminated zone thicknesses are required, one each for the surface and subsurface soil source terms.

Vertically, the radiologically significant material associated with the subsurface soil source term is located just beneath the cover (approximately 5 feet bgs) and lies in a lens that is nominally about 4 feet (1.2 meters) thick (Figure 5–3). The amount of source material deposited rapidly depletes as the depth increases and terminates at a maximum thickness of approximately 15 feet in one location. RESRAD does not offer a recommended (or default) distribution for the thickness of contaminated zone parameter (THICK0).

A lognormal-N distribution best describes the observed variability in the depth profile for the subsurface soil source term and thus the thickness of the contaminated zone. In describing the source term for input to RESRAD, the thickness parameter is represented by a bounded lognormal-N distribution, with the central tendency (CT) value conservatively set to a thickness of 4 feet (1.22 meters). This thickness is conservative in that the mean source thickness over the entire footprint of the cell, the impacted area, is considerably less than 4 feet. It is only within the region along the former haul road (the most heavily contaminated area) that the thickness averages approximately 4 feet. The distribution is bounded at a minimum value of 0 feet (0 meters), and a maximum value of 15 feet (4.5 meters). Sensitivity analysis showed that annual dose was insensitive to the thickness of the subsurface soil contaminated zone. This is the result of the self-attenuating effect of source thicknesses greater than approximately 12 inches (0.3 meters) coupled with the attenuating capacity of the engineered clay cover. Figure 5–27 graphically illustrates the distribution from which values of the contaminated zone thickness parameter are sampled when modeling the subsurface source term.

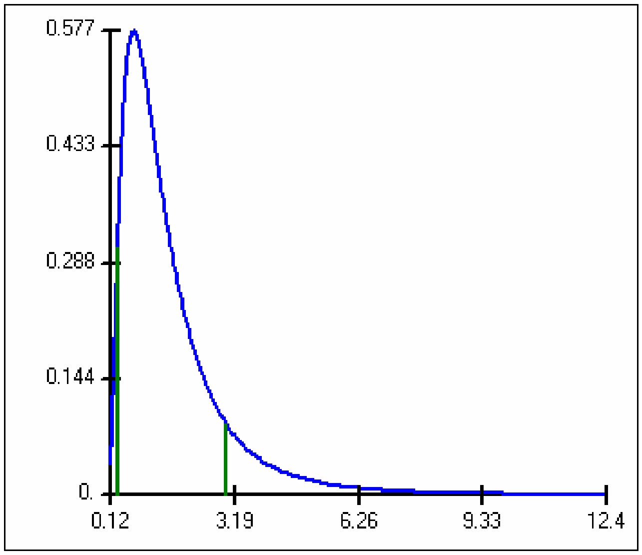

Figure 5–27 Subsurface Soil Contaminated Zone Thickness (m)

The very nature of the deposition process leading to a hypothesized surface soil source term requires that the thickness of the surface soil source term be quite small. In fact, mass balance considerations described in Section 5.2.1.2 support the conclusion that the thickness of the surface soil contaminated zone could not reasonably be greater than approximately 2 cm, in even the most implausible of situations. The theoretically derived amount of core spoil materials from which the surface soil source term is bounded. As a result, there is a logical inverse relationship between the areal distribution of the surface soil source term and its thickness.

In acknowledgement of these bounding limitations, the surface soil contaminated zone thickness is conservatively represented with a triangular distribution having a mode of 0.001m and ranging from 0 to 0.02m. In addition, the surface soil contaminated zone thickness is inversely correlated with its area. Figure 5–28 graphically illustrates the distribution from which values of the surface soil contaminated zone thickness parameter are sampled.

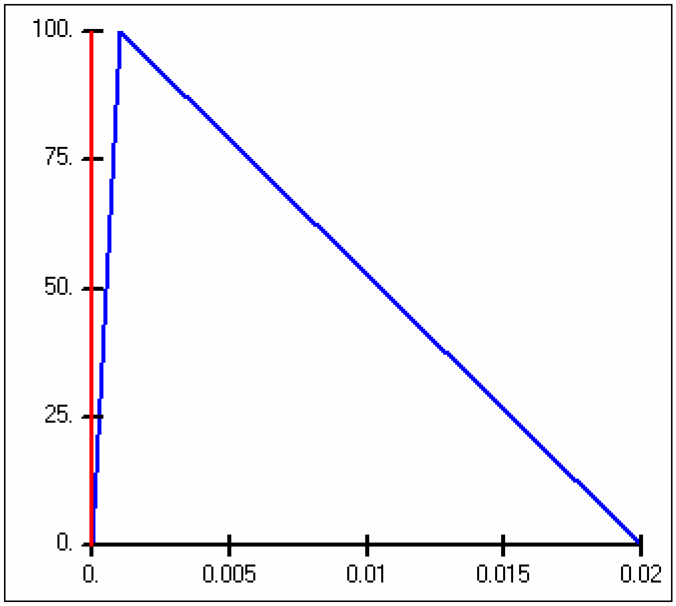

Figure 5–28 Surface Soil Contaminated Zone Thickness (m)

5.8.4.19 Contaminated Zone Density

The subsurface soil contaminated zone is comprised of thorium-bearing slag materials interspersed with other debris and sandy materials associated with the sand cover layer. The density of the native sand materials found at the site was measured to arrive at a site-specific estimate of the sand layer soil density. It is conservatively assumed that the subsurface soil contaminated zone has a soil density (and other hydrogeologic soil properties) equal to that of the native sand materials at the site. The measured sandy soil density was found to be 1.65 g/cm^3, a number typical of sandy soils. Sensitivity analysis showed that annual dose was insensitive to a wide range of soil densities. The subsurface soil contaminated zone density (DENSCZ) was represented with a truncated normal distribution (the RESRAD default). The mean was set equal to the measured density of sandy materials at the site (1.65 g/cm^3) and allowed to range between approximately 1.25 and 2.05 g/cm^3. Figure 5–29 graphically illustrates the distribution from which values of the subsurface soil contaminated zone density were sampled.

When modeling the surface soil source term, the contaminated zone density is highly influenced by the density of the engineered clay cover layer with which it would be in contact. Realistically, the surface soil contamination layer, if it exists at all, would be composed of a very thin surface veneer of the clay cover material into which radioactive residues have been mingled. Since sensitivity analysis shows that annual dose is insensitive to a wide range of soil densities, the surface soil contaminated zone soil density has been represented with a single-point deterministic estimate of 1.97 g/cm^3.

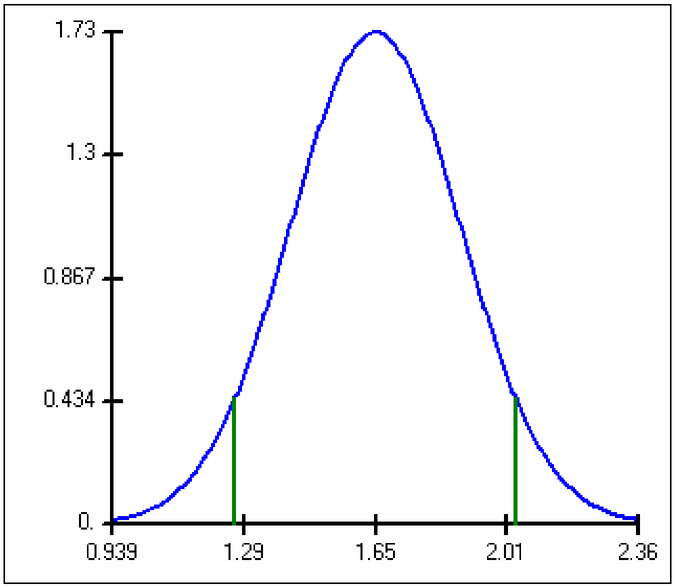

Figure 5–29 Subsurface Soil Contaminated Zone Density (g/cm^3)

5.8.4.20 Contaminated Zone Hydraulic Conductivity

RESRAD uses vertical hydraulic conductivity to model the potential vertical movement of water through the contaminated layer and any underlying strata. Hydraulic conductivity is a key parameter used to assess the downward vertical migration potential of radioactivity released from the contaminated zone layer. This allows RESRAD to calculate the potential concentration of residual radioactivity in a useable subsurface saturated zone. Sensitivity analysis showed that annual dose is insensitive to a wide range of hydraulic conductivities in the contaminated zone, largely because the thorium and other radionuclides in the contaminated zone are physically and chemically bound up in the slag and because the slag is very insoluble. When modeling the surface soil source term, the fact that the potential volume and thickness of the source term are very small makes the annual total effective dose equivalent even less sensitive to the hydraulic conductivity parameter. Consequently, the more conservative approach is to presume that the residual radioactivity in the surface soil source term has a low hydraulic conductivity and, thus, remains present on the surface where there is a greater potential for human exposure. The RESRAD deterministic default parameter was used to represent the hydraulic conductivity associated with the surface soil source term.

In consideration of the voluminous source term associated with the subsurface soil contaminated zone, hydraulic conductivity in that layer is described with a probabilistic distribution. Hydraulic conductivity was specifically measured for the native sand materials found at the site and was determined to be 6.4 x 10^{-3} cm/s (≈2000 m/y). Hydraulic conductivity in the subsurface soil contaminated zone (HCCZ) and the underlying unsaturated zone 1 (HCUZ(1)) are represented with bounded lognormal-N distributions (the RESRAD default) having central tendency values at 2,000 meters per year and with values conservatively ranging over two decades between 200 and 20,000 meters per year (Figure 5–30).

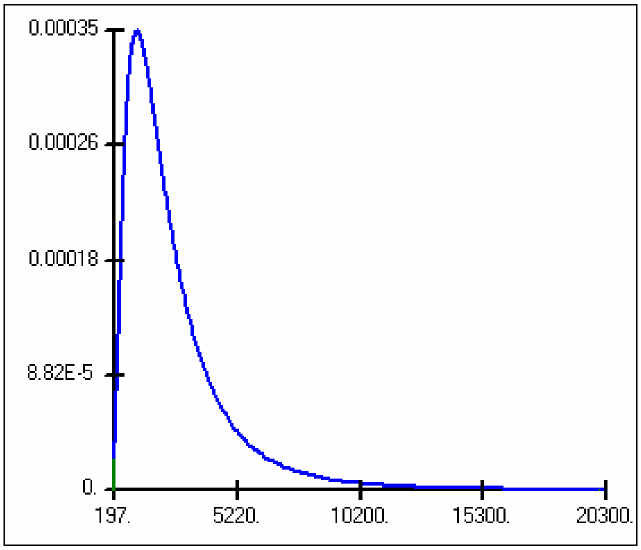

Figure 5–30 Hydraulic Conductivity (m/y)

5.8.4.21 Soil Specific b-Parameter

The soil-specific exponential b-parameter is one of several hydrogeologic parameters used to calculate radionuclide transport from the contaminated zone. Sensitivity analysis showed that annual dose was insensitive to both the contaminated zone and saturated zone b-parameters (BCZ and BSZ, respectively), thus, the RESRAD default distribution (bounded lognormal-N) and parameters were used when modeling the subsurface soil source term. Figure 5–31 graphically illustrates the distribution from which values of the contaminated zone soil b-parameter are sampled. The soil b-parameter is physically limited to values less than approximately 15 (as represented by the vertical red line in Figure 5–31). Again, the RESRAD deterministic default was used when modeling the surface soil source term.

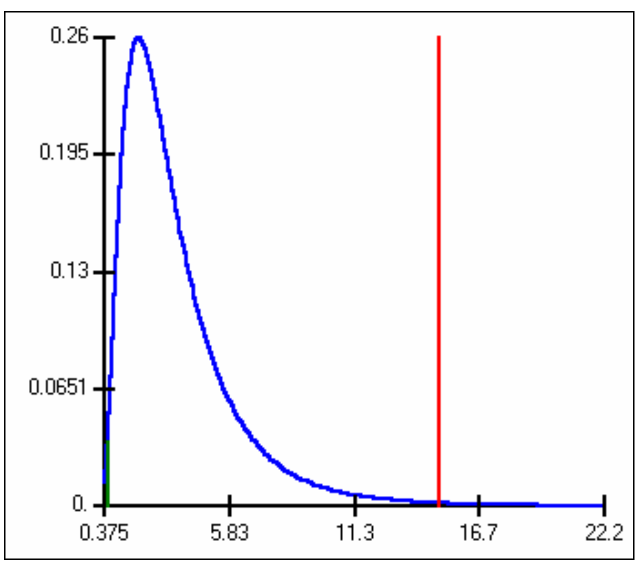

Figure 5–31 Soil Specific b-Parameter (dimensionless)

5.8.4.22 Thorium Distribution Coefficient, Contaminated Zone

Distribution coefficients (Kd) describe the partitioning between solid (soil) and liquid phases of soluble concentrations of radionuclides introduced to a soil column. It is a key parameter influencing the migration of radioactivity from contaminated zone soils to groundwater. Distribution coefficients for a given chemical species (e.g., uranium) can vary over many orders of magnitude depending on the soil type, pH, redox potential, and presence of other ions. Observed Kd values for thorium are somewhat less subject to extreme variability.

The distribution coefficient, Kd, is the ratio of the mass of solute species adsorbed or precipitated on the solids per unit of dry mass of the soil to the solute concentration in liquids within the pore spaces in the soil. The key component of this definition as it relates to the site-specific conditions at the site and the RESRAD groundwater transport model is that it assumes that the radionuclide is introduced to the soil column as a solute. While this classical approach may be appropriate to describe the retardation of soluble contaminant migration in the soil column beneath the contaminated soil layer, it fails to address the situation encountered for the so-called “contaminated zone.” The site-specific condition encountered at the Tobico Site is that the physical composition of the contaminant is a vitreous slag that is essentially insoluble even under the most extreme in-situ conditions that might reasonably be encountered.

As discussed previously in Section 3 of this Decommissioning Plan, leachability studies performed on comparable thorium-bearing slag found at other locations affirm that very little thorium is expected to be leached out of the slag in the environment. In addition, radiological analysis of leachate samples collected from within the engineered cell support the conclusion that thorium is not readily leached from the slag found at the MDNR site (MACTEC 2002). Given that radio-analytical measurements of the leachate in the cell indicate that radiological contaminants are not present in concentrations greater than that found naturally occurring in unaffected groundwater, the effective Kd value of the contaminated zone is judged to be substantially greater than the RESRAD default value which is derived from data based upon adsorption measurements.

The Kd value for thorium in both of the “contaminated zones” is described using the RESRAD default, lognormal-N distribution function, except that bounds have been established on the range of values sampled during probabilistic analysis (a bounded lognormal-N distribution). The central tendency value for the distribution has been set to match the default, single-point estimate used in the RESRAD deterministic module, 60,000 cm^3/g (Yu 1993, NRC 1980). Probabilistic sampling is bounded between 3,200 and 89,000 cm^3/g, the lowest and highest geometric mean values for various soils as reported in literature and summarized in the Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil (Yu 1993). Treatment of the contaminated zone Kd value for thorium in this manner is only slightly less conservative than the default treatment of this parameter in RESRAD’s probabilistic module and is at least as conservative as the default treatment in RESRAD’s deterministic module. A graphic representation of the probability density function describing the thorium Kd parameter for the surface soil and subsurface soil contaminated zones in the RESRAD probabilistic module is offered in Figure 5–32. The vertical green lines represent the bounding conditions at 3,200 and 89,000 cm^3/g as described. Annual effective dose equivalent is not sensitive to variability in thorium Kd over the wide range considered in the probabilistic assessment.

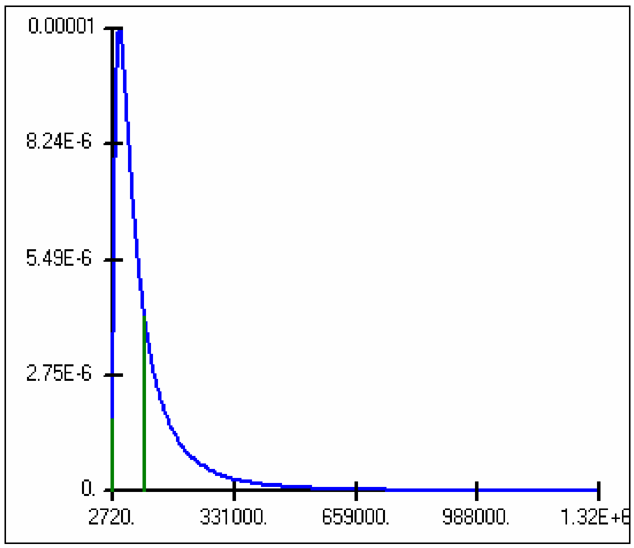

Figure 5–32 Distribution Coefficient—Thorium (cm^3/g)

5.8.4.23 Thickness of the (Underlying) Waste Layer

As represented in Figure 5–6, the underlying waste layer has a slightly different thickness depending upon whether the surface or subsurface soil contaminated zone is being considered. In the geophysical abstraction used to model to surface soil source term, the waste layer is the entire thickness beneath the engineered clay cover and above the undisturbed glacial till layer and is identified in the RESRAD model as "unsaturated layer #2." When considering the subsurface soil source term, the underlying waste layer is only that portion of the soil column that underlies the subsurface contaminated zone and is identified in the RESRAD model as "unsaturated layer #1."

When modeling the subsurface soil source term, the underlying waste layer—unsaturated layer #1—is comprised of the sand cover layer and the non-radiological waste materials lying above the undisturbed native till. The sand layer was placed over existing waste materials at the direction of the State of Michigan and prior to slag disposal at the site. From a modeling perspective, the hydro-geologic properties of this layer are characterized as consistent with the sand material, as this represents the most conservative characterization of the layer. Further, the layer is actually saturated as opposed to unsaturated as its name implies.[7] The thickness of unsaturated layer #1 varies inversely with the thickness of the contaminated zone such that the combined thickness of the contaminated zone and unsaturated layer #1 totals approximately 4 meters (13 feet). Sensitivity analysis showed that the annual dose was not sensitive to unsaturated zone thickness. Unsaturated layer #1 thickness (H(1)) is represented with a bounded lognormal-N distribution (the RESRAD default), with a most likely value of 1.52 meters (5 feet) and a range of 0.5 to 4 meters. The H(1) and THICK0 parameters have been inversely correlated in the RESRAD uncertainty analysis (a conservative treatment) to force thinner thicknesses of the underlying unsaturated layer when the contaminated layer is thicker. Figure 5–33 graphically illustrates the distribution from which values of unsaturated layer #1 thickness are sampled.

When modeling the surface soil source term, the waste layer—unsaturated layer #2—is comprised of the entire soil column underlying the engineered clay cover layer and lying above the undisturbed native till. This layer includes the slag disposal layer, the sand cover layer, and the non-radiological waste materials. The overall thickness of this layer is nominally about 4 meters thick. Unsaturated layer #2 thickness (H(2)) is represented with a bounded lognormal-N distribution (the RESRAD default), with a most likely value of 4 meters (13 feet) and a range of 3 to 5 meters. Figure 5–34 graphically illustrates the distribution from which values of unsaturated layer #2 thickness are sampled.

7 RESRAD accommodates only one "saturated" layer, at least in name. This is, in part, because RESRAD is not designed nor intended to be a comprehensive groundwater fate and transport model and does not seek to model the lateral dispersion of radionuclides. Rather, RESRAD seeks to model the vertical migration of radionuclides from the source term (contaminated zone) through intermediate "unsaturated layers" and into the "saturated layer" from which it is assumed that drinking water may be drawn. This is ideal as long as the groundwater nearest to the ground surface (the uppermost saturated layer) is a potential source is drinking water. This is not the case at the Tobico Marsh Site where the near surface soils are actually saturated and yet are not a viable source of drinking water. RESRAD can easily accommodate this situation by modeling intermediate layers with hydraulic parameters that are characteristic of saturated zones even though RESRAD names such a layer as an "unsaturated zone." This is what has been done in the case of the Tobico Marsh SGA site modeling.

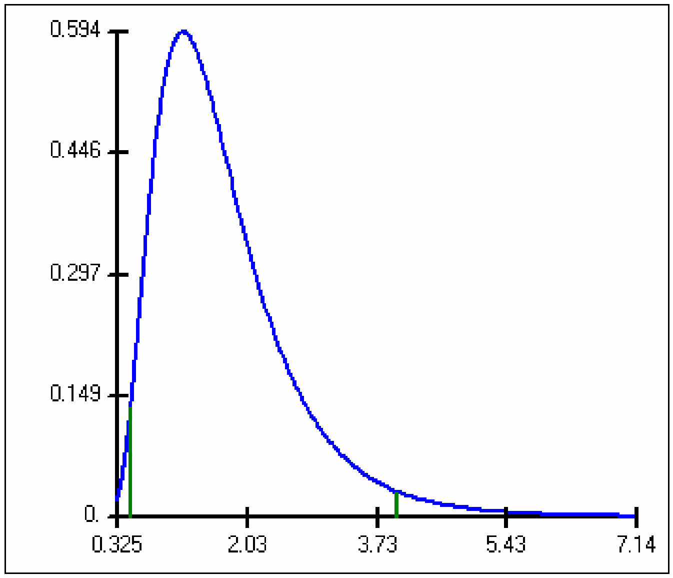

Figure 5–33 Thickness of Underlying Waste Layer—Subsurface Soil Source Term (m)

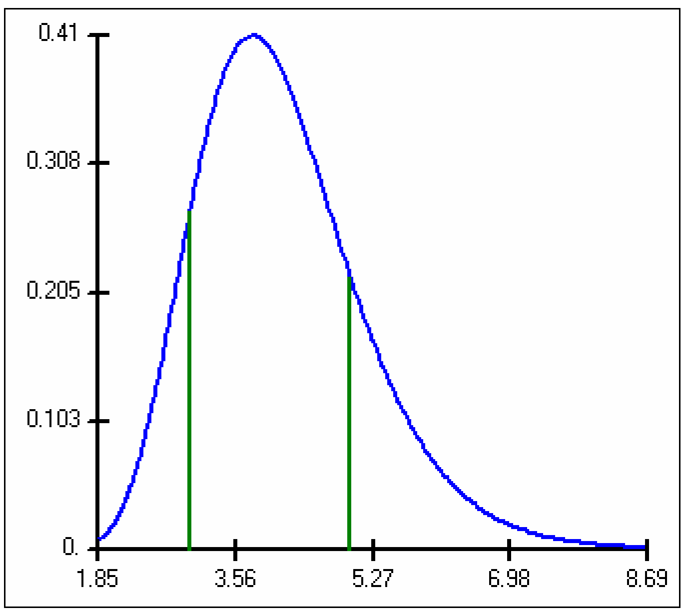

Figure 5–34 Thickness of Underlying Waste Layer—Surface Soil Source Term (m)

5.8.4.24 Density, Underlying Waste Layer

As described above, when modeling the subsurface soil source term, the underlying waste layer—unsaturated layer #1—is comprised, in part, of sand materials placed over non-radioactive waste materials. The density of this layer is conservatively estimated to be equal to the measured density of native sand materials at the site, 1.65 g/cm^3 (Cabrera 2001). The same truncated normal distribution used to describe the density of the subsurface soil contaminated zone (see Figure 5–29) is again used to describe the density of the underlying waste layer, unsaturated layer #1 (DENSUZ(1)). Projected annual dose equivalent is insensitive to variation in the density of the unsaturated layer #1 over a wide range of reasonable soil densities.

When modeling the surface soil source term, the measured density of native sand materials at the site, 1.65 g/cm^3, is used as a single point estimate in the RESRAD deterministic module. Uncertainty in this parameter was shown to be unimportant to the outcome of the surface soil source term modeling.

5.8.4.25 Hydraulic Conductivity, Underlying Waste Layer

The hydraulic conductivity of the underlying waste layer (unsaturated layer #1, HCUZ(1), when modeling the subsurface soil source term and unsaturated layer #2, HCUZ(2), when modeling the surface soil source term) is also conservatively linked to the measured hydraulic conductivity of the native sand materials. The same bounded lognormal-N distribution used to describe the hydraulic conductivity of the subsurface soil contaminated zone (see Figure 5–30) is used to describe the hydraulic conductivity of unsaturated layer #1 when modeling the subsurface soil source term and unsaturated layer #2 when modeling the surface soil source term. The most likely value described by the distribution is 2,000 meters per year. Projected annual dose equivalent is insensitive to variation in the hydraulic conductivity of the underlying waste layer over a two decade range of values from 200 to 20,000 m/y.

5.8.4.26 Thorium Distribution Coefficients, All Underlying Layers

The thorium distribution coefficients for all layers underlying the contaminated zones (including both saturated and unsaturated layers) has been set to the RESRAD probabilistic default distribution and values. The default provides a wide range of possible values from which the uncertainty analysis is performed with a central tendency of approximately 6,000 cm^3/g (an order of magnitude more conservative than the RESRAD deterministic module default value of 60,000 cm^3/g). Sensitivity analysis showed that annual dose is not particularly sensitive to variability in the thorium distribution coefficient within any of the saturated or unsaturated layers. Figure 5–35 graphically illustrates the range from which values of thorium distribution coefficient within each of the various saturated and unsaturated layers [(DCACTU1, DCACTU2, DCACTU3, and DCACTS] are sampled.

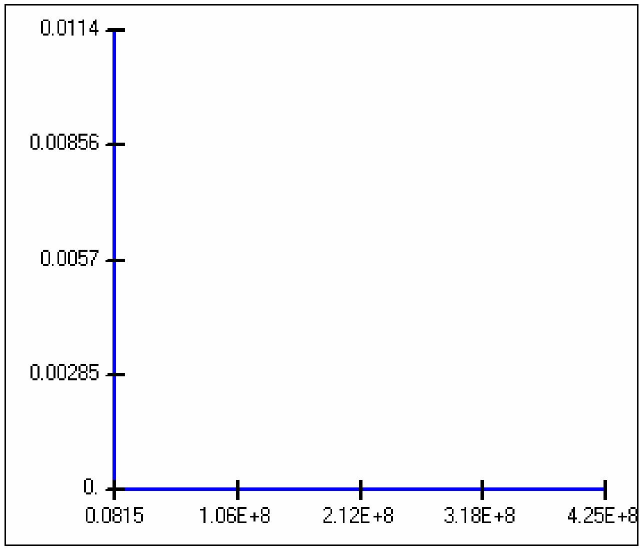

Figure 5–35 Distribution Coefficient, All Underlying Layers—Thorium (cm^3/g)

5.8.4.27 Thickness of the Undisturbed Glacial Till Layer

The thickness of undisturbed glacial till layer (unsaturated layer #2 [H(2)] when modeling the subsurface soil source term, and unsaturated layer #3 [H(3)] when modeling the surface soil source term) varies from ≈50 to 100 feet (15.25 to 30.5 meters). Sensitivity analysis showed that annual dose equivalent was insensitive to variability in the thickness of the undisturbed glacial till layer. The thickness is represented with a bounded lognormal-N distribution (the RESRAD default), with a most likely value (18.2 meters) near the lower end of the range that extends from 15.25 to 30.5 meters. Figure 5–36 graphically illustrates the distribution from which values of the undisturbed glacial till layer thickness are sampled.

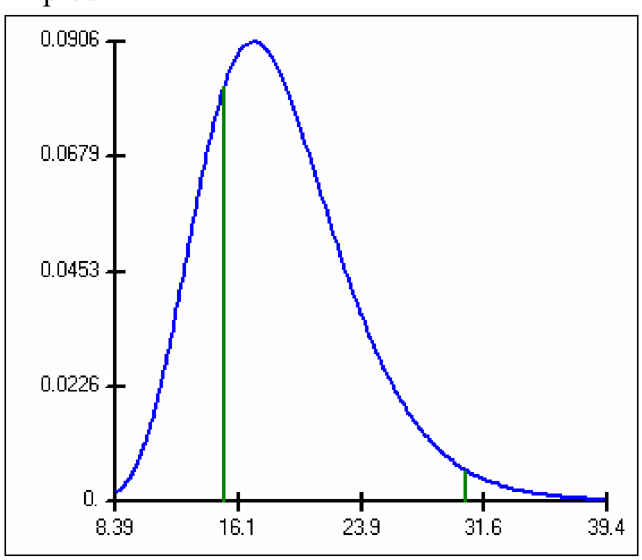

Figure 5–36 Thickness of Undisturbed Glacial Till Layer (m)

5.8.4.28 Density, Undisturbed Glacial Till Layer

As described earlier, unsaturated zone 2 is comprised of the undisturbed glacial till layer underlying the entire area. This layer is very dense with clay soils. The soil density of native clay bearing soils at the site was measured to arrive at a site-specific estimate of the soil density of the undisturbed, clay-bearing, native till layer underlying the Site (unsaturated layer #2). The measured soil density was found to be 1.97 g/cm^3, a number typical of high clay content soils (Cabrera 2001). Sensitivity analysis showed that annual dose was insensitive to a wide range of soil densities. Since site-specific data was available for the density of the clay bearing materials at the site, it was used to describe the density of the native till layer. Unsaturated layer #2 soil density (DENSUZ(2)) was represented with a truncated normal distribution (the RESRAD default). The Mean was set equal to the measured density of 1.97 g/cm^3 and allowed to range between approximately 1.6 and 2.4 g/cm^3. This is the same distribution used to represent the soil density of the engineered clay cover and is presented in Figure 5–21.

5.8.4.29 Hydraulic Conductivity, Undisturbed Glacial Till Layer

Hydraulic conductivity was specifically measured for the native clay-bearing materials found at the site and was determined to be 5.4 x 10^{-8} cm/s (≈0.017 m/y) (Cabrera 2001). Hydraulic conductivity in undisturbed glacial till layer [HCUZ(2)] is represented with a bounded lognormal-N distribution (the RESRAD default) having a central tendency value at 0.017 meters per year and with values conservatively ranging over two decades between 0.17 and 17 centimeters per year (Figure 5–37). Sensitivity analysis showed that annual dose was insensitive to a wide range of hydraulic conductivities, largely because the thorium and other radionuclides in the contaminated zone are physically and chemically bound up in the slag and because the slag is very insoluble.

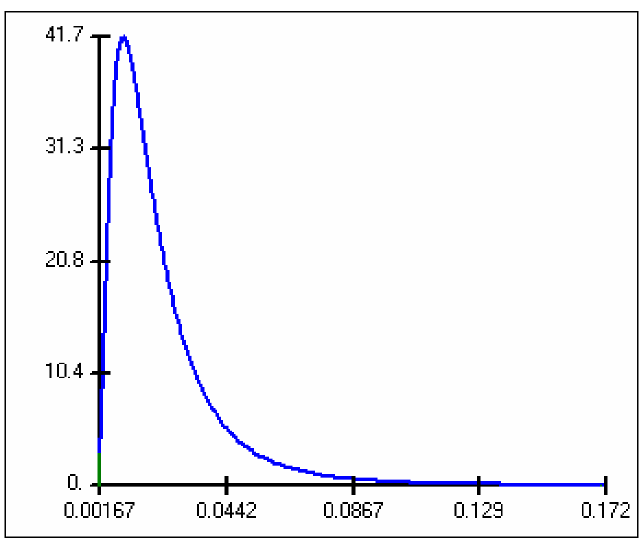

Figure 5–37 Hydraulic Conductivity, Undisturbed Glacial Till Layer (m/y)

5.8.4.30 Density, Saturated Zone

The RESRAD default distribution and fit for the saturated zone density is used in the uncertainty analysis because no site-specific data was collected explicitly for this parameter. The truncated normal distribution is centered at the most likely value of 1.52 g/cm^3 and ranges between values of less than 1 and 2.2 g/cm^3. Variability in the saturated zone soil density was shown to have no affect on the projected annual dose in the uncertainty analysis. Figure 5–38 graphically illustrates the distribution from which values of saturated zone density are sampled.

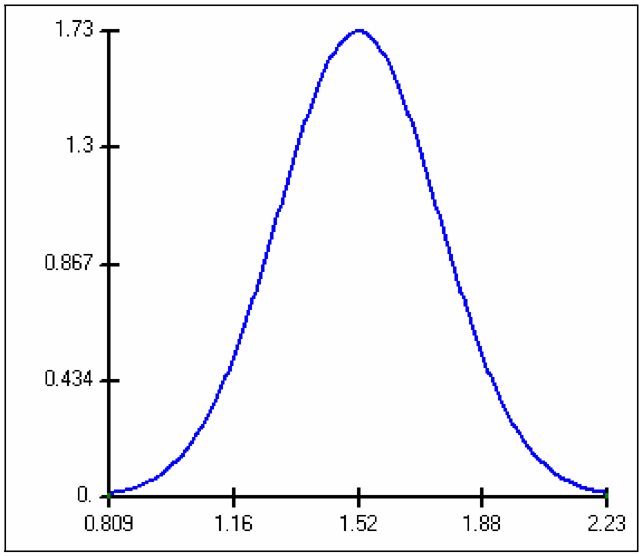

Figure 5–38 Saturated Zone Soil Density (g/cm^3)

5.8.4.31 Hydraulic Conductivity, Saturated Zone

The RESRAD default distribution and fit for the saturated zone hydraulic conductivity (HCSZ) is used in the uncertainty analysis as no site-specific data was collected explicitly for this parameter. The bounded lognormal-N distribution is centered at the most likely value of 10 meters per year and ranges over more than five decades of possible values between approximately 1.5 cm/y and more than 6,700 m/y. Variability in the saturated zone hydraulic conductivity was shown to have no measurable impact on the projected annual dose in the uncertainty analysis. Figure 5–39 graphically illustrates the distribution from which values of saturated zone hydraulic conductivity are sampled.

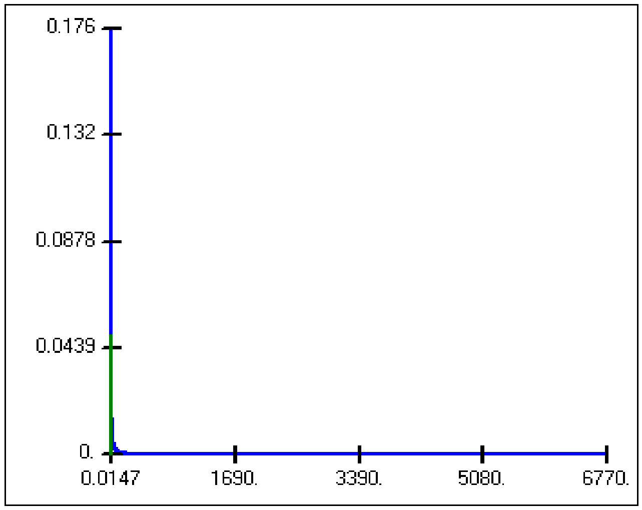

Figure 5–39 Hydraulic Conductivity, Saturated Zone (m/y)

5.8.4.32 Saturated Zone Hydraulic Gradient

The hydraulic gradient is one of several hydrogeologic parameters used to calculate radionuclide transport from the contaminated zone. Sensitivity analysis, again, showed that annual dose was insensitive to the hydraulic gradient parameter (HGWT). The RESRAD default probabilistic distribution (bounded lognormal-N) and parameters were used when modeling the subsurface soil source term. The central tendency value is estimated to be 0.006 and the distribution is allowed to range over approximately 4 decades from 0.00007 to 0.5. Figure 5–40 graphically illustrates the distribution from which values of the hydraulic gradient parameter are sampled. When modeling the surface soil source term, the RESRAD default deterministic value was used.

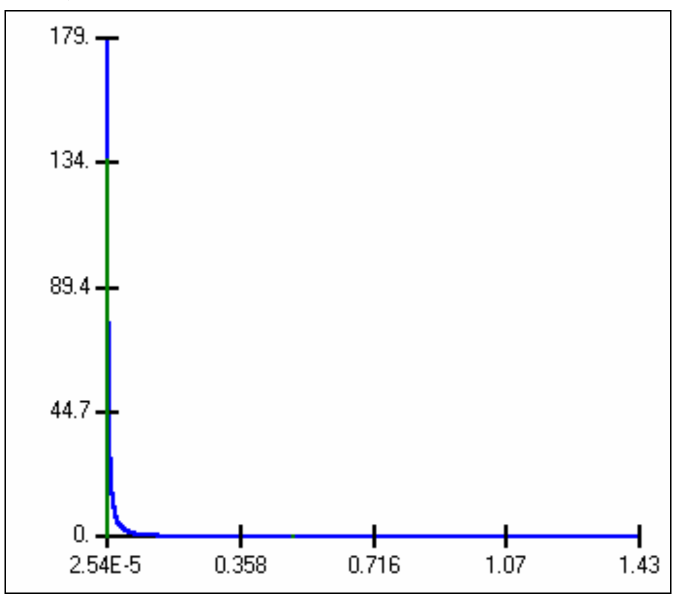

Figure 5–40 Hydraulic Gradient (dimensionless)

5.8.5 Interpreting Uncertainty Analysis Results

Since the results of the uncertainty analyses provide a distribution of annual doses, it must be recognized that some percentage of the calculated doses may exceed the regulatory limit. At the same time, because not all parameter distributions are symmetrical and because some parameters are correlated, the mean dose calculated in the uncertainty analysis is not necessarily equal to a deterministic dose calculated using single point estimates of the various parameters. A further phenomenon observed in the probabilistic modeling is that the mean dose for a particular series of repetitions is frequently higher than the 90th or even the 95th percentile estimates of probable dose. This results when all but the rarest combinations of very conservative estimates of the individual parameters result in little or no dose. In the very few cases in which the Monte Carlo sampling technique selects combinations of values from the outermost extremes of the proposed parameter distributions, projected annual dose is large compared to the majority of cases sampled. The resulting cumulative probability density curve reveals an extremely skewed distribution of projected future dose. An example of this phenomenon as seen in the probabilistic dose modeling of the composite recreational user scenario is evident in Figure 5–41. Here the cumulative probability for annual dose from all nuclides and all pathways is essentially 100% at an annual dose of nearly zero. Yet, there are four samples (out of 1,500 combinations tested) that yielded an estimate of annual dose between 2 and 5 mrem per year. The mean dose is highly influenced by these four results, which themselves represent less than 1% of the estimates. In the case of the composite recreational user scenarios the mean annual dose is calculated to be 9.3 $x10^{-3}$ mrem/year while the 90th and 95th percentile estimates are 8.4 $x10^{-4}$ and 2.3 x 10^{-3} mrem/year, both substantially less than the calculated and reported mean.

A key issue that must be addressed in the treatment of uncertainty is specifying how to interpret the results from an uncertainty analysis in the context of the deterministic regulatory limit. There is no such thing as absolute assurance that the regulatory limit will be met, so regulatory compliance must be stated in terms of a metric of the distribution. Even for a deterministic analysis, it should be recognized that the reported dose is simply one of a range of possible doses that could be calculated for the Site and scenario. In this analysis, the peak of the mean dose for the critical exposure group (the most exposed subpopulation) is presented for comparison with the deterministic regulatory limit as required by regulation. But, since the severely skewed cumulative distribution phenomenon occurs repeatedly in the annual dose modeled for the Tobico Site using the probabilistic approach, a suite of projected annual doses corresponding to the 50th, 90th, 95th, and maximum is reported along with the traditional compliance measure, peak mean annual dose. In addition, the deterministic estimate of projected annual dose is provided for comparison.

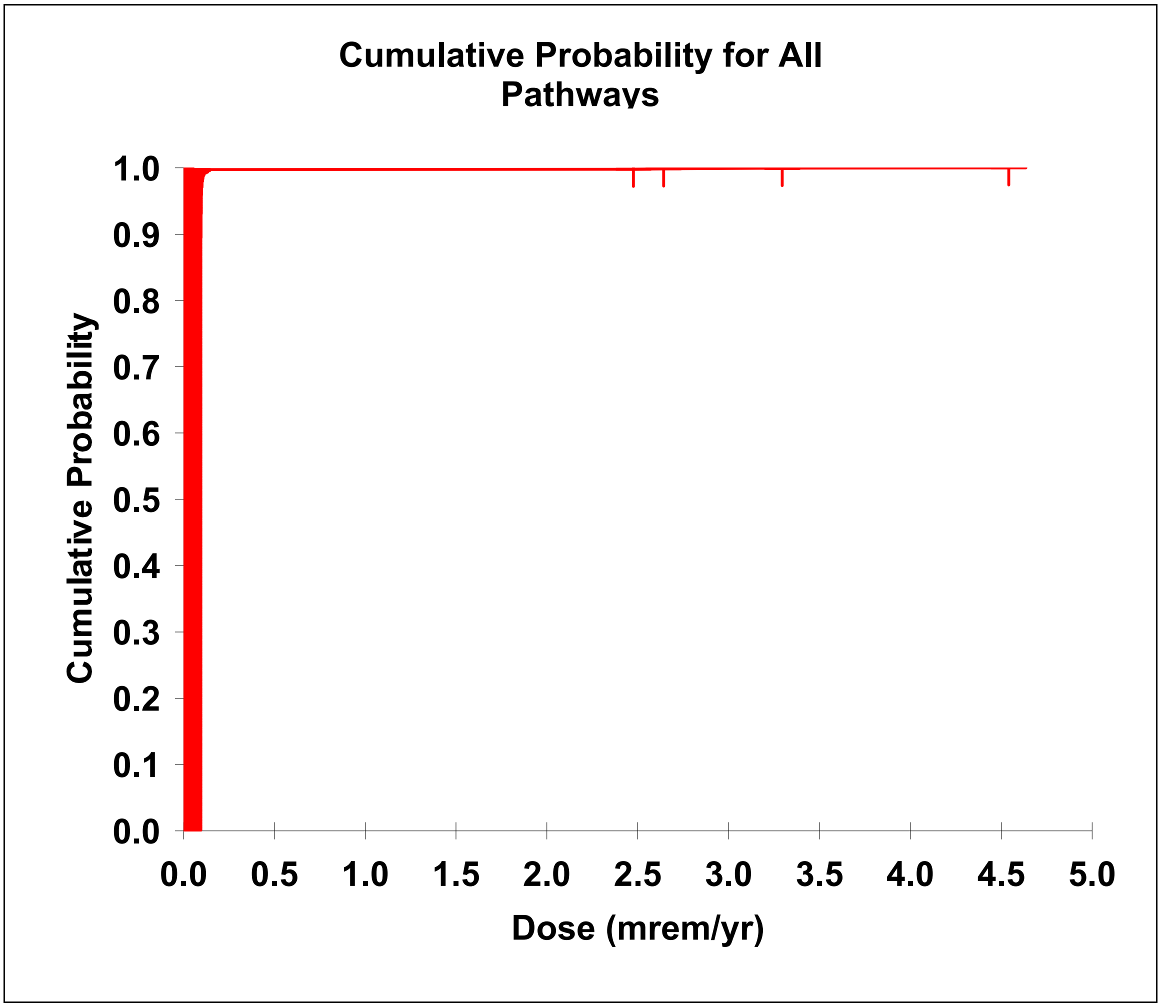

Figure 5–41 Cumulative Probability Plot—Annual Dose, All Pathways (Composite Recreational User Scenario)

Risk managers should keep in mind that the parameters used to perform the assessment were selected to represent the critical exposure group (analogous to the Reasonable Maximum Exposure concept), and as such already overstate the expected dose to the average receptor at the Site. Results of both the deterministic and probabilistic dose modeling including an evaluation of the uncertainty analyses are presented in sections that follow.

5.9 RESULTS OF COMPUTER MODELING

In order to evaluate the DCGLs, the computer modeling codes were iteratively run for each of the selected scenarios to arrive at the highest uniform concentration of residual radioactivity in soil that results in a peak mean annual dose estimate to a single receptor in the critical exposure group that is equal to the regulatory limit (25 mrem/y)[8]. The computer code was set up to model each scenario with the input parameters identified and explained in this section. Separate runs, using the proposed suite of exposure scenarios, were setup for the surface and subsurface soil source terms. A separate set of DCGLs are presented for each scenario and for each source term.

The following sections present the results of the computer modeling relating Th-232 source concentrations in soil with potential future doses in each of the four scenarios evaluated.

5.9.1 Subsurface Soil Source Term

The subsurface soil source term is presented first as it is the primary source term at the site.

5.9.1.1 Recreational Hunter Scenario

The recreational hunter scenario is considered, perhaps, to be the most likely among the future use scenarios considered for this site. Whereas the variety of persons who engage in recreational hunting on the site might spend little time actually on the site, the critical exposure group receptor for this scenario is a conservatively assumed to spend a relatively large fraction of his/her available recreational hunting time actually on the site where the greatest exposure potential occurs. This naturally provides a conservative evaluation of the potential future dose for a more typical hunter making use of the site.

Table 5-13 summarizes the results of modeling the projected future exposure potential for the scenario involving exposure while engaged in recreational hunting at the Site. The isotope mixtures used are typical of, and consistent with, the measured isotopic mixture in soil at the site (Cabrera 2001). The Th-230 to Th-232 ratio used (3.1:1) is derived using a volume-weighted calculation that takes into account the range and volumetric significance of measured ratios found at the site. The volume-weighted approach is technically superior to an approach that relies simply upon a mean statistic with an associated confidence interval.

A review of the computer modeling printouts for the recreational hunter scenario (Appendix A) reveals that exposure from gamma radiation dominates the potential future dose. The Th-232 and Th-228 isotopes are the most significant contributors to total effective annual dose[9]. Figure 5–42 and Figure 5–43 illustrate the relative pathway and

8 The concentration of residual radioactivity in the subsurface soil source term reached the specific activity limit for Th-232 without producing 25 mrem/y to the average member of the critical exposure group in each of the proposed scenarios. Therefore, the potential annual dose is reported for the subsurface soil term with residual radioactivity concentration at the specific activity limit.

9 A review of Figure 5–43 reveals the relative impotency of Th-230 to contribute significantly to total annual effective dose equivalent as compared with Th-232 and Th-228 (which, for the purpose of dose modeling, are assumed to be in equilibrium). This relative impotency of Th-230 further adds to the weight of evidence supporting the idea that a volume-weighted solution to the Th-230:Th-232 ratio is appropriate. Even if the worst-case ratio measured in a single sample from the site (11:1) were used in dose modeling, there would be little impact on the projected annual dose.

isotopic contributions to total effective dose equivalent for the recreational hunter scenario.

Table 5-13 Recreational Hunter Scenario—Subsurface Soil Source Term

Statistic	Projected Annual Dose (mrem/year)
Annual Dose Limit (10 CFR 20.1401, 1402)	25.0
Peak Mean Annual Dose	0.000752
50^{th} Percentile	0.00000792
90^{th} Percentile	0.000811
95^{th} Percentile	0.00269
Maximum Annual Dose	0.0792
Deterministic Estimate, Peak Annual Dose	5.8×10^{-6}
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix A.	

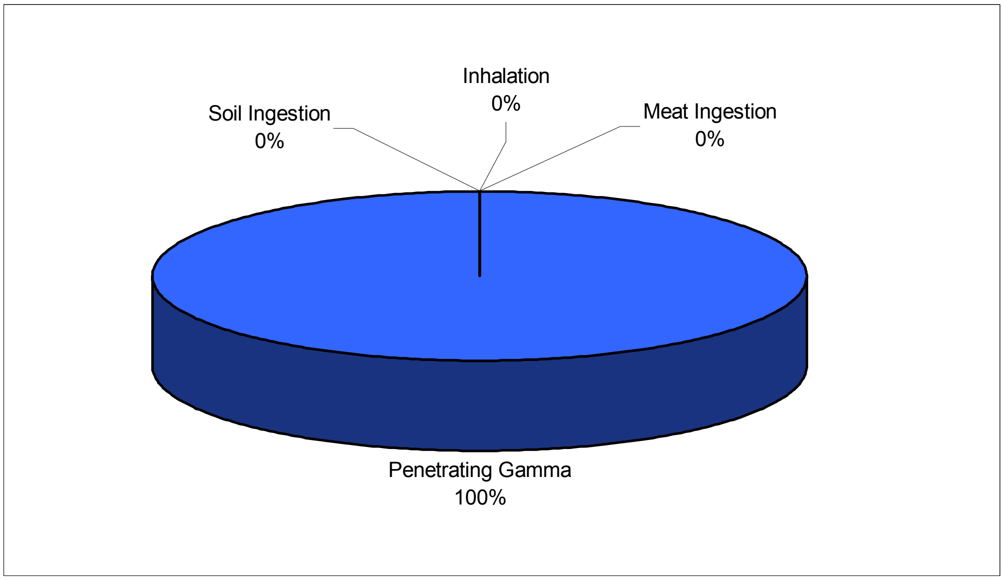

Figure 5–42 Pathway Contributions to Subsurface Source Term TEDE—Recreational Hunter

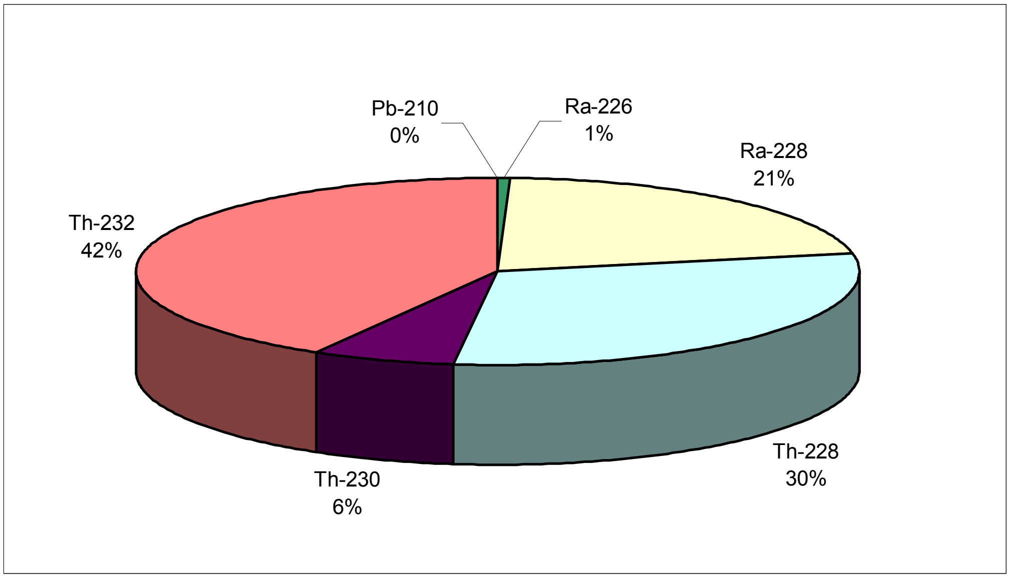

Figure 5–43 Isotopic Contributions to Subsurface Source Term TEDE—Recreational Hunter

5.9.1.2 Naturalist Scenario

Table 5-14 summarizes the results of modeling the projected future exposure potential for the scenario involving exposure while engaged in nature viewing at the site. The isotope mixtures used are consistent from one scenario to the next and consistent with the measured isotopic mixture in soil at the site.

Table 5-14 Naturalist Scenario—Subsurface Soil Source Term

Statistic	Projected Annual Dose (mrem/year)
Annual Dose Limit (10 CFR 20.1401, 1402)	25.0
Peak Mean Annual Dose	0.000752
50th Percentile	0.00000792
90th Percentile	0.000811
95th Percentile	0.00269
Maximum Annual Dose	0.0792
Deterministic Estimate, Peak Annual Dose	5.8×10^{-6}
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix B.	

A review of the computer modeling printouts for the naturalist scenario (Appendix B) reveals that exposure from gamma radiation again dominates the potential future dose. The Th-232 and Th-228 isotopes are the most significant contributors to total effective annual dose. In fact, the relative contributions to total annual dose by isotope are consistent with the results from the recreational hunter scenario because neither the meat ingestion pathway nor the plant ingestion pathway contributes significant dose to either total. Figure 5–44 and Figure 5–45 illustrate the relative pathway and isotopic contributions to total effective dose equivalent for the naturalist scenario.

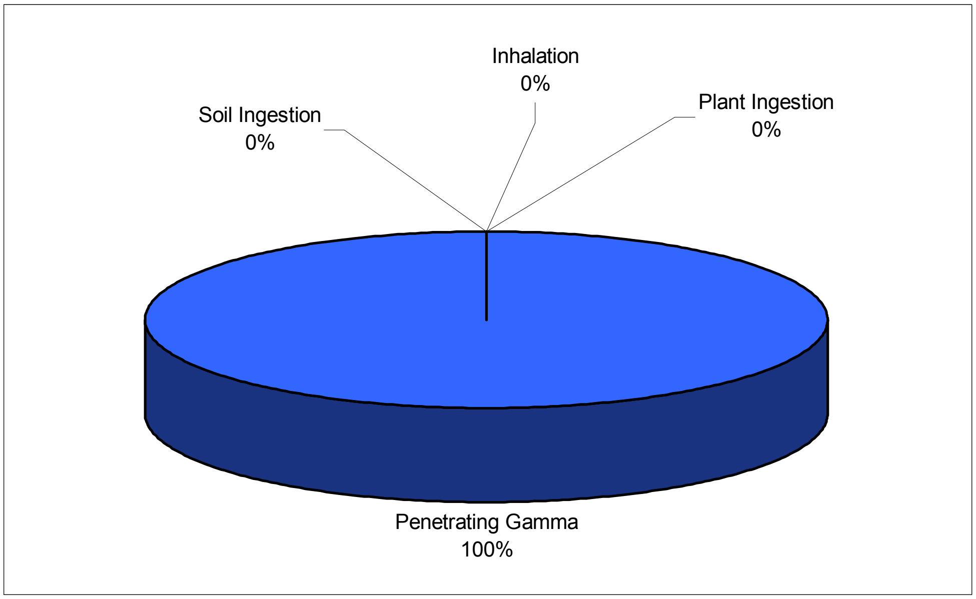

Figure 5–44 Pathway Contributions to Subsurface Source Term TEDE—Naturalist

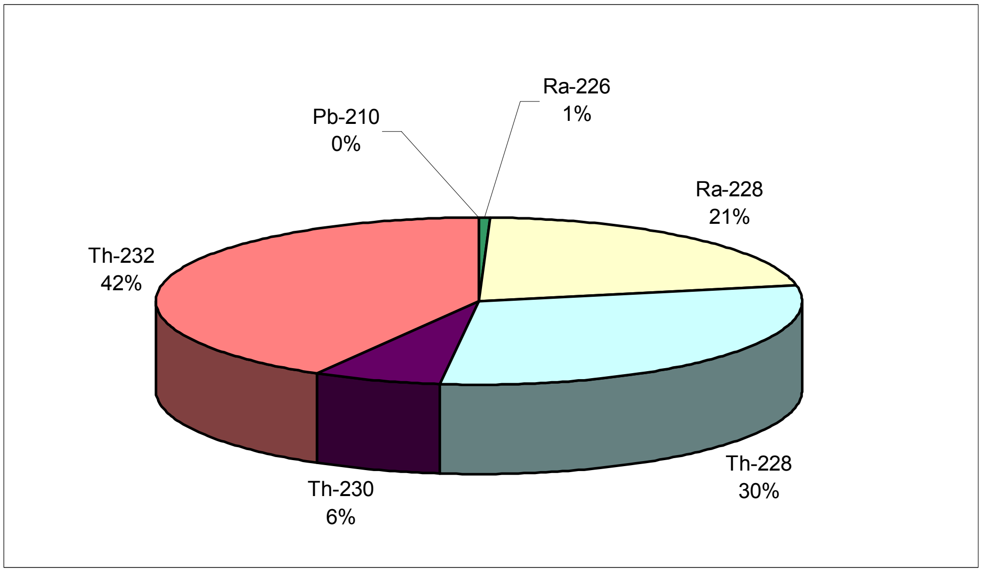

Figure 5–45 Isotopic Contributions to Subsurface Source Term TEDE—Naturalist

5.9.1.3 Recreational Fisher Scenario

The recreational fisher scenario evaluates the potential exposure to receptors that could be expected to frequent the property to fish. It was conservatively assumed that as much as 100% of the fisher's aquatic foods diet could be derived from waters on the site that are impacted with residual radioactivity.

Table 5-15 summarizes the results of modeling the projected future exposure potential for the scenario involving exposure while engaged in recreational fishing at the site. The isotope mixtures used are consistent from one scenario to the next and consistent with the measured isotopic mixture in soil at the site.

Table 5-15 Recreational Fisher Scenario—Subsurface Soil Source Term

Statistic	Projected Annual Dose (mrem/year)
Annual Dose Limit (10 CFR 20.1401, 1402)	25.0
Peak Mean Annual Dose	0.0301
50th Percentile	0.00000807
90th Percentile	0.000841
95th Percentile	0.00298
Maximum Annual Dose	23.3
Deterministic Estimate, Peak Annual Dose	5.8×10^{-6}
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix C.	

A review of the computer modeling printouts for the recreational fisher scenario (Appendix C) reveals that exposure from gamma radiation is consistent with that calculated in the recreational hunter and naturalist scenarios but that dose from the aquatic foods ingestion pathway is significant when the considering the extreme quantile estimates (>99th percentile) of dose. In fact, because of the extreme skewness in projected dose from the aquatic foods ingestion pathway, both the maximum and peak annual dose is dominated by the aquatic foods ingestion pathway in the out years approaching 100 years. Th-232 is the most significant contributor to total effective annual dose. Figure 5–46 and Figure 5–47 illustrate the relative pathway and isotopic contributions to total effective dose equivalent for the recreational fisher scenario.

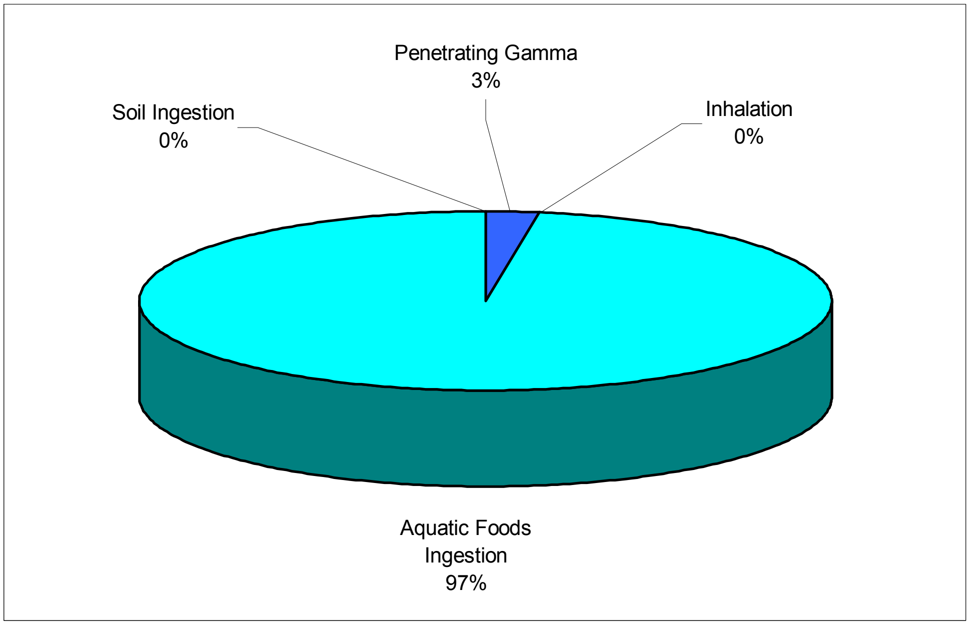

Figure 5–46 Pathway Contributions to Subsurface Source Term TEDE—Recreational Fisher

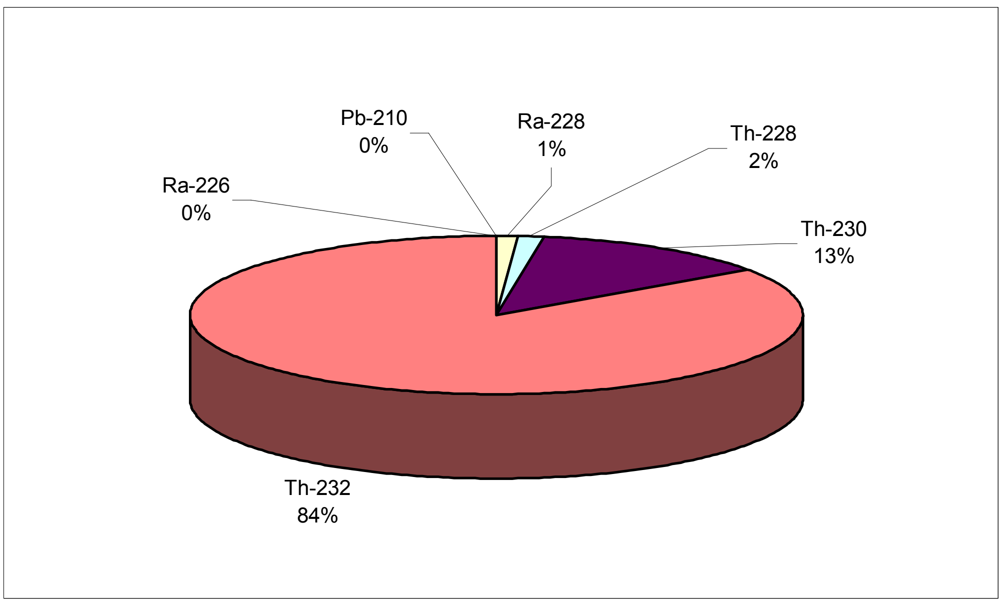

Figure 5–47 Isotopic Contributions to Subsurface Source Term TEDE—Recreational Fisher

5.9.1.4 Composite Recreational User Scenario

The composite recreational user scenario serves as a bounding condition scenario and evaluates the potential exposure to receptors that could be expected to frequent the site to hunt, fish, and view nature. The hypothetical receptor consumes plant food grown on the site, meat harvested from the site, and aquatic foods caught from the waters of the site.

Table 5-16 summarizes the results of modeling the projected future exposure potential for the scenario involving exposure while engaged in multiple recreational activities at the site. The isotope mixtures used are consistent from one scenario to the next and consistent with the measured isotopic mixture in soil at the site.

Table 5-16 Composite Recreational User Scenario—Subsurface Soil Source Term

Statistic	Projected Annual Dose (mrem/year)
Annual Dose Limit (10 CFR 20.1401, 1402)	25.0
Peak Mean Annual Dose	0.0093
50^{th} Percentile	0.00000799
90^{th} Percentile	0.000856
95^{th} Percentile	0.00245
Maximum Annual Dose	4.54
Deterministic Estimate, Peak Annual Dose	5.8×10^{-6}
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix D.	

A review of the computer modeling printouts for the composite recreational user scenario (Appendix D) reveals that exposure from gamma radiation is consistent with that calculated in the recreational hunter and naturalist scenarios, but, like the recreational fisher scenario, dose from the aquatic foods ingestion pathway is significant when the considering the extreme quantile estimates (>99th percentile) of dose. In fact, because of the extreme skewness in projected dose from the aquatic foods ingestion pathway, both the maximum and peak annual dose is dominated by the aquatic foods ingestion pathway in the out years approaching 100 years. Th-230 is the most significant contributor to total effective annual dose. Figure 5–48 and Figure 5–49 illustrate the relative pathway and isotopic contributions to total effective dose equivalent for the composite recreational user scenario.

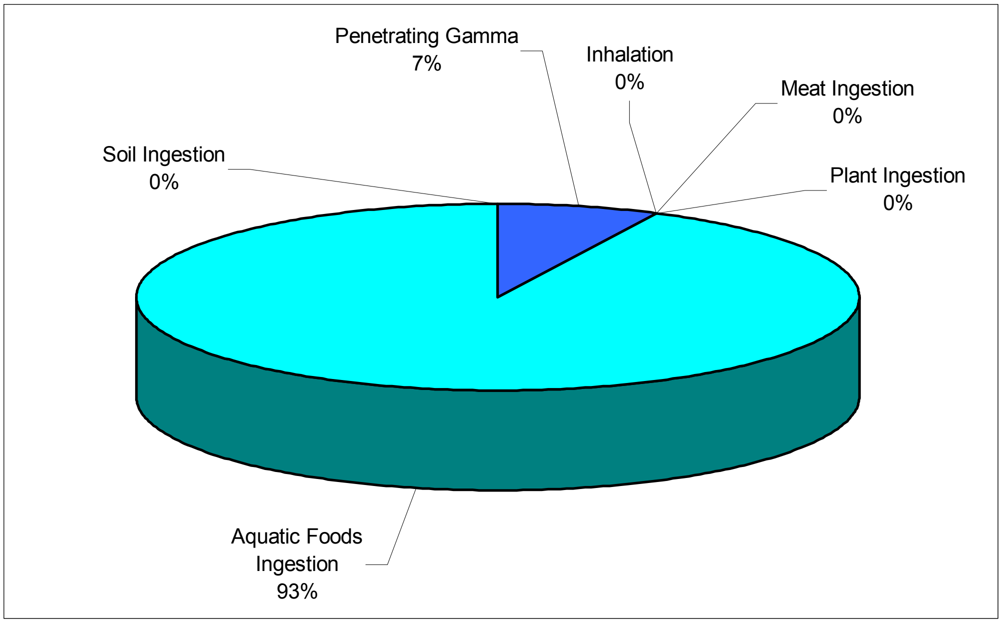

Figure 5–48 Pathway Contributions to Subsurface Source Term TEDE—Composite Recreational User

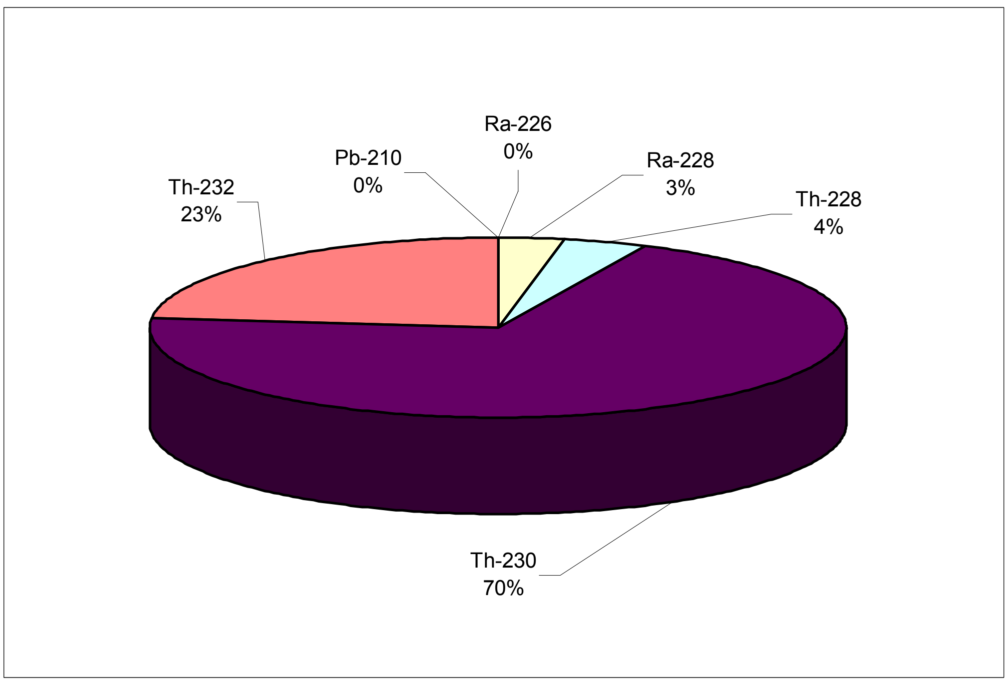

Figure 5–49 Isotopic Contributions to Subsurface Source Term TEDE—Composite Recreational User

5.9.2 Surface Soil Source Term

The surface soil source term is a relatively small volume, hypothetical source term and is thus considered as the secondary source term at the site. However, because it is represented as lying on the immediate surface of the engineered clay cover, humans may come into direct contact with the residual radioactivity. Additionally, the surface soil source term does not have the advantage of the attenuating effect of the of an overlying clay cover material to retard penetrating gamma radiation flux. As a result, the concentration of residual radioactivity associated with thoriated slag corresponding to the decommissioning dose limit of 25 mrem/y is appreciably smaller than that associated with the subsurface soil source term. This means that the DCGL for the surface soil source term is smaller than that for the subsurface soil source term.

To arrive at a DCGL for the surface soil source term, the RESRAD input files used to assess each of the four exposure scenarios for the subsurface soil source term were modified to adequately depict the surface soil source term. While some changes were necessary in the source term abstraction and the geophysical descriptions of the various "layers" used in the RESRAD model in order to accommodate the evaluation of the surface soil source term, the overall exposure scenarios were unchanged.

5.9.2.1 Recreational Hunter Scenario

Table 5-17 summarizes the results of modeling the projected future exposure potential from surface soil contamination for the recreational hunting scenario at the Site.

Table 5-17 Recreational Hunter Scenario—Surface Soil Source Term

Statistic	Projected Annual Dose (mrem/year)
Annual Dose Limit (10 CFR 20.1401, 1402)	25.0
Peak Mean Annual Dose	25.0
50th Percentile	22.3
90th Percentile	48.9
95th Percentile	56.7
Maximum Annual Dose	84.4
Deterministic Estimate, Peak Annual Dose	32.0
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix E.	

A review of the computer modeling printouts for exposure to the surface soil source term in the recreational hunter scenario (Appendix E) reveals that exposure from gamma radiation dominates the potential future dose. The Th-228 and Ra-228 isotopes are the most significant contributors to total effective annual dose. Figure 5–50 and Figure 5–51 illustrate the relative pathway and isotopic contributions to total effective dose equivalent for the recreational hunter scenario.

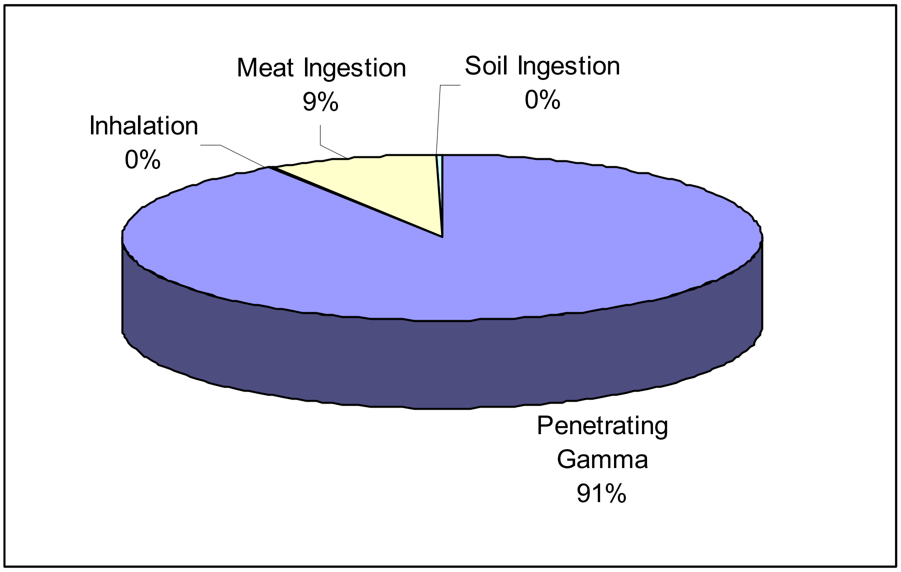

Figure 5–50 Pathway Contributions to Surface Source Term TEDE—Recreational Hunter

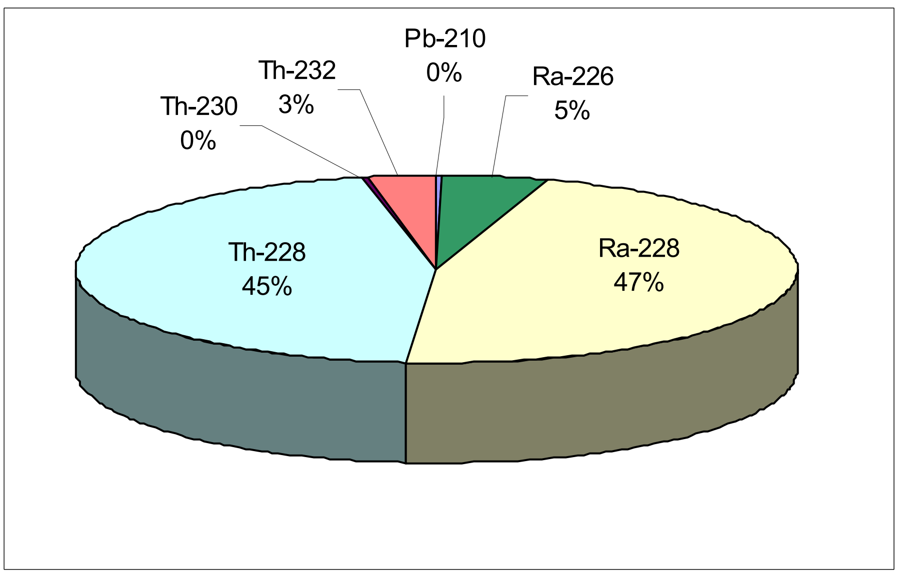

Figure 5–51 Isotopic Contributions to Surface Source Term TEDE—Recreational Hunter

5.9.2.2 Naturalist Scenario

Table 5-18 summarizes the results of modeling the projected future exposure potential from surface soil contamination for the scenario involving exposure while engaged in nature viewing at the site.

Table 5-18 Naturalist Scenario—Surface Soil Source Term

Statistic	Projected Annual Dose (mrem/year)
Annual Dose Limit (10 CFR 20.1401, 1402)	25.0
Peak Mean Annual Dose	25.0
50th Percentile	21.9
90th Percentile	49.0
95th Percentile	57.5
Maximum Annual Dose	97.5
Deterministic Estimate, Peak Annual Dose	27.6
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix F.	

A review of the computer modeling printouts for exposure to the surface soil source term in the naturalist scenario (Appendix F) reveals that exposure from gamma radiation again dominates the potential future dose. Dose from the plant ingestion pathway does contribute an appreciable amount to the projected annual dose. The Th-228 and Ra-228 isotopes are, again, the most significant contributors to total effective annual dose. Figure 5–52 and Figure 5–53 illustrate the relative pathway and isotopic contributions to total effective dose equivalent for the naturalist scenario when modeling the surface soil source term.

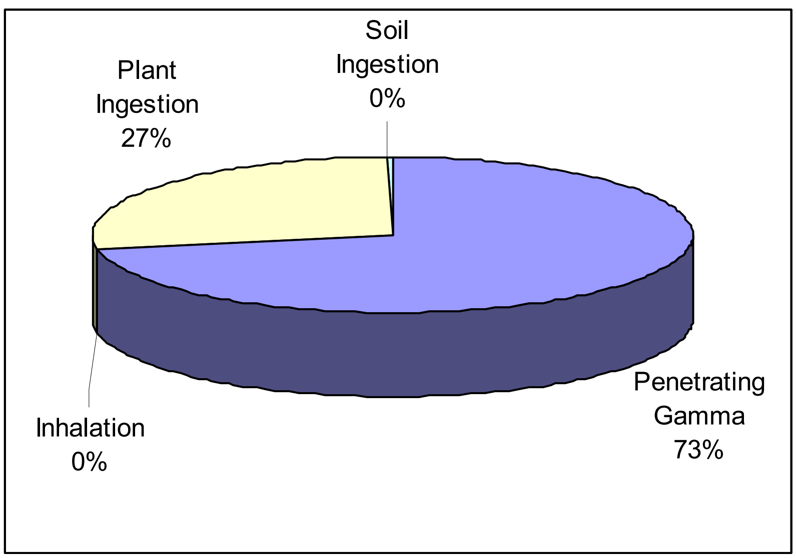

Figure 5–52 Pathway Contributions to Surface Source Term TEDE—Naturalist

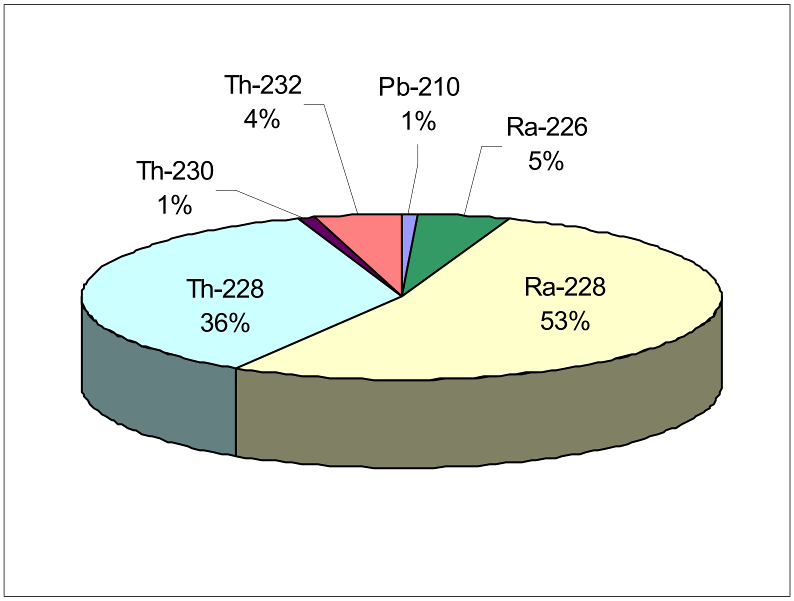

Figure 5–53 Isotopic Contributions to Surface Source Term TEDE—Naturalist

5.9.2.3 Recreational Fisher Scenario

The recreational fisher scenario evaluates the potential exposure to receptors that could be expected to frequent the property to fish. Table 5-19 summarizes the results of modeling the projected future exposure potential from surface soil contamination for the scenario involving exposure while engaged in recreational fishing at the site.

Table 5-19 Recreational Fisher Scenario—Surface Soil Source Term

Statistic	Projected Annual Dose (mrem/year)
Annual Dose Limit (10 CFR 20.1401, 1402)	25.0
Peak Mean Annual Dose	25.0
50^{th} Percentile	22.3
90^{th} Percentile	48.9
95^{th} Percentile	56.7
Maximum Annual Dose	84.4
Deterministic Estimate, Peak Annual Dose	33.6
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix G.	

A review of the computer modeling printouts for exposure to the surface soil source term in the recreational fisher scenario (Appendix G) reveals that exposure from penetrating gamma radiation pathway is the most significant dose production pathway. Accordingly, Th-228 and Ra-228 are again the most significant contributors to total effective annual dose. Figure 5–54 and Figure 5–55 illustrate the relative pathway and isotopic contributions to total effective dose equivalent for the recreational fisher scenario.

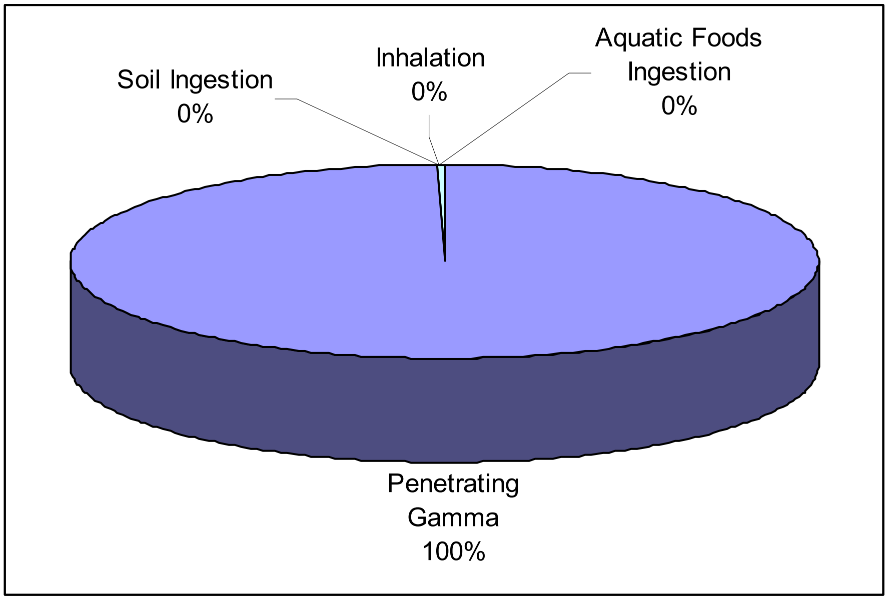

Figure 5–54 Pathway Contributions to Surface Source Term TEDE—Recreational Fisher

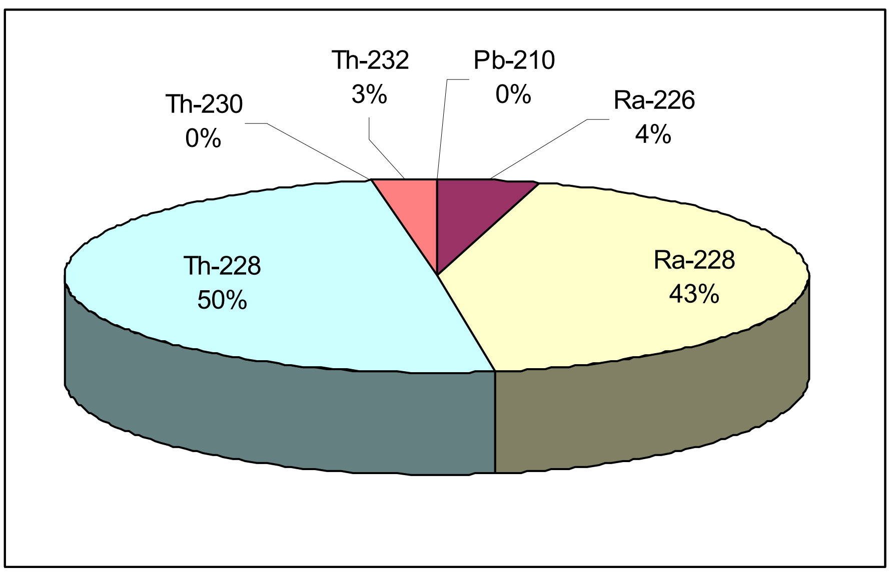

Figure 5–55 Isotopic Contributions to Surface Source Term TEDE—Recreational Fisher

5.9.2.4 Composite Recreational User Scenario

The composite recreational user scenario serves as a bounding condition scenario and evaluates the potential exposure to receptors that could be expected to frequent the site to hunt, fish, and view nature. The hypothetical receptor consumes plant food grown on the site, meat harvested from the site, and aquatic foods caught from the waters of the site.

Table 5-20 summarizes the results of modeling the projected future exposure potential from surface soil contamination for the scenario involving exposure while engaged in multiple recreational activities at the site.

Table 5-20 Composite Recreational User Scenario—Surface Soil Source Term

Statistic	Projected Annual Dose (mrem/year)
Annual Dose Limit (10 CFR 20.1401, 1402)	25.0
Peak Mean Annual Dose	25.0
50th Percentile	22.0
90th Percentile	48.7
95th Percentile	58.0
Maximum Annual Dose	113.0
Deterministic Estimate, Peak Annual Dose	26.9
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix H.	

A review of the computer modeling printouts for exposure to the surface soil source term in the recreational hunter scenario (Appendix H) reveals that exposure from gamma radiation dominates the potential future dose. Nearly 30% of the total annual effective dose is contributed via the plant ingestion pathway, while meat and fish consumption produce only minor fractions. The Th-228 and Ra-228 isotopes are, again, the most significant contributors to total effective annual dose. Figure 5–56 and Figure 5–57 illustrate the relative pathway and isotopic contributions to total effective dose equivalent for the composite recreational user scenario when modeling the surface soil source term.

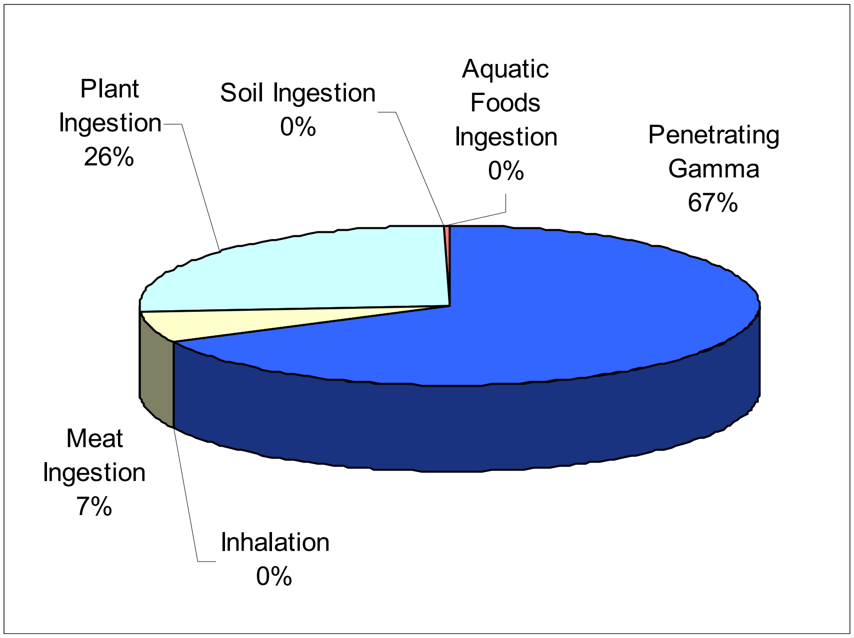

Figure 5–56 Pathway Contributions to Surface Source Term TEDE—Composite Recreational User

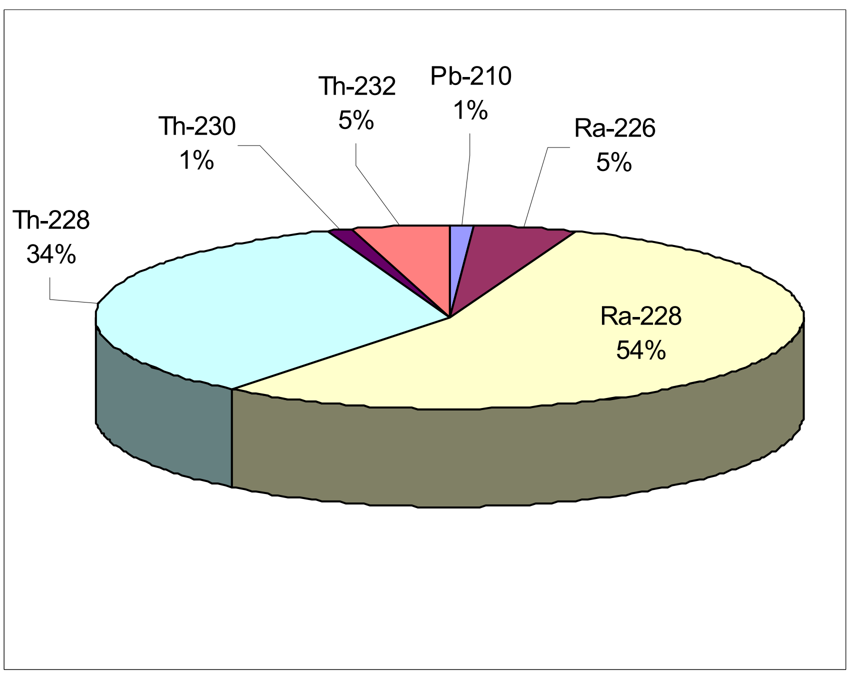

Figure 5–57 Isotopic Contributions to Surface Source Term TEDE—Composite Recreational User

5.9.3 Potential for the Migration of Radioactivity Offsite

The radioactivity at the Tobico Marsh SGA Site has been shown (at present) to be confined laterally to the area circumscribed by the installed slurry walls and vertically to the contaminated layer just beneath the cover.

The potential for dose to an offsite receptor resulting from the migration of radioactivity offsite is constrained by the surface soil erosion rate (coupled with the cover thickness) and by the ability of radioactivity to migrate through groundwater.[10] By considering the radionuclide concentrations in various media (e.g., surface water, surface soil, etc.) projected for 1,000 years into the future, the potential for offsite dose can reasonably be eliminated. The RESRAD output reports (Part IV) for each of the four scenarios evaluated (See Appendices A-H, Part IV, Detailed Concentrations and Radionuclides Report) shows that at no time over the 1,000 year outlook period are concentrations of radionuclides projected to be present in either environmental media or in foodstuffs. The absence of radioactivity in these media, while taking into account the potential erosion of the cover and the mobility of radionuclides in groundwater, suggest that offsite dose is not a concern even if the slurry walls should leak. Sampling from within the cell itself has shown that concentrations of radioactivity in the leachate are not practically different from those in unaffected background groundwater samples (MACTEC 2002).

5.10 SUMMARY OF MODELING RESULTS

The estimates of peak mean dose to the critical exposure groups in each of the foregoing scenarios have been derived with industry standard modeling tools specifically designed to assess exposures to residual radioactivity. The RESRAD modeling code is recognized as an industry standard, and is accepted for use by the USNRC, USDOE, and USEPA for modeling dose and risk to individuals exposed to radioactivity originating in soils.

Conservatism has been built into the modeling by conscientiously selecting exposure factor values that err on the side of safety when confronted with uncertainty in the selection of input parameters. In order to provide the risk managers and decision makers with insight as to the degree of conservatism associated with the dose modeling, projected annual doses have been calculated with both deterministic and probabilistic techniques.

Based on the results presented above, the subsurface soil source term in each of the scenarios considered is projected to produce a peak mean annual dose well below the annual public dose limits identified by the USNRC (10 CFR 20.1402) even when the residual radioactivity concentration is set at the specific activity limit for Th-232. The central tendency concentration associated with the surface soil source term would have to exceed 350 pCi/g Th-232 in order to produce the potential for a receptor to receive as much as the annual public dose limit identified by the USNRC, even in the most unlikely and conservative of the scenarios evaluated. In addressing the DCGL allocation concept

10 It is important to note that the RESRAD dose modeling performed does not assume the ability of the slurry walls to impede or retard lateral movement of radioactivity through groundwater.

described in Section 5.2.1, it is clear that, on average, only a very small fraction of one millirem per year is likely to result from exposure to residual radioactivity in the subsurface source term in any of the scenarios evaluated. Thus, realistically, all of the allowable 25 mrem/y under the decommissioning standard could safely be allocated to the surface soil source term, without undue risk of exceeding the decommissioning standard's annual dose limit for unrestricted release.

The dose evaluation described in this report provides the risk managers and decision makers with the substantive basis necessary to set and approve site-specific permissible concentration standards, the DCGLs, derived from the applicable regulatory limits for public dose.

The projected annual dose arising from the subsurface soil source term is not constrained by the permissible decommissioning dose standard of 25 mrem/y but rather, the potential annual dose is constrained to a value substantially lower than the decommissioning annual dose limit by virtue of the physically limiting specific activity for Th-232. That the residual radioactivity concentration in the subsurface soil source term could safely approach the specific activity limit without impacting compliance, provides the risk managers and decision makers with a clear margin of safety upon which to evaluate public health impacts resulting from exposure to residual radioactivity at the site.

As for the surface soil source term, the $DCGL_W$ is constrained by the permissible decommissioning dose standard of 25 mrem/y.

Additionally, the projected peak annual dose for each scenario has been derived with a level of conservatism commensurate with the extent of the hazard and uncertainty in the estimation tools.