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Revision 1

Dose Calculation Methodology for Liquid Waste Performance Assessments at the Savannah River Site

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REVISION SUMMARY

REV. #	DESCRIPTION	DATE OF ISSUE
0	Initial Issue	22 May 2013
1	Revisions to: • improve documentation of assumptions, • improve documentation of parameter development, • apply a more consistent approach to the development of parameter values (e.g., ensure all parameter values developed based on consistent application of assumptions), and • correct errors identified in Revision 0.	31 July 2014

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ACRONYMS/ABBREVIATIONS

BDCF	Biosphere Dose Conversion Factor
DCF	Dose Conversion Factor
DOE	U.S. Department of Energy
EDF	Effective Dose Factor
EPA	U.S. Environmental Protection Agency
FTF	F-Tank Farm
GM	Geometric Mean
GSD	Geometric Standard Deviation
HTF	H-Tank Farm
ICRP	International Commission on Radiological Protection
IHI	Inadvertent Human Intruder
INEEL	Idaho National Engineering and Environmental Laboratory
LADTAP	Liquid Annual Dose to All Persons
MOP	Member of the Public
N/A	Not Applicable
PA	Performance Assessment
SD	Standard Deviation
SDF	Saltstone Disposal Facility
SL	Seepline (used to indicate stream water at the point of groundwater confluence)
TC	Transfer Coefficient (or Transfer Factor)

1.0 INTRODUCTION

The purpose of this report is to describe dose calculations and document recommendations for dose calculation parameters for use in Liquid Waste performance assessments (PAs) at the U.S. Department of Energy (DOE) Savannah River Site. The methodology described herein builds on the dose calculations and methods applied within the current Liquid Waste PAs: the HTF PA, the FTF PA, and the SDF PA. This methodology is not intended to invalidate or supersede existing PAs, rather this report provides recommendations for process improvements based on recent information and improved systemic understanding. Table 1.0-1 provides a list of each current Liquid Waste PA.

Table 1.0-1: Current Liquid Waste Performance Assessments

Facility	Document ID	Revision	Title
HTF	SRR-CWDA-2010-00128	1	Performance Assessment for the H-Area Tank Farm at the Savannah River Site
FTF	SRS-REG-2007-00002	1	Performance Assessment for the F-Tank Farm at the Savannah River Site
SDF	SRR-CWDA-2009-00017	0	Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site

The calculations described in this report may be used to determine radiological doses to two types of hypothetical receptors: the Member of the Public (MOP) and the Inadvertent Human Intruder (IHI). These receptors receive dose via exposure pathways. A set of exposure pathways that contribute to dose is called an exposure scenario.

Sections 1.1, 1.2, and 1.3 below, provide a high-level definition of the human receptors, description of the exposure scenarios that are assumed in this dose calculation methodology, and an overview of the contaminant and dose processes, respectively. Section 2 of this report provides an overview of the methodology described herein and a brief history of the evolution of Liquid Waste PA dose calculations. Section 2.1 is a primer for reading the equations contained within this report. Sections 3 through 6 provide all of the dose equations needed to determine doses based on each exposure scenario. Finally, Section 7 provides a complete listing of recommended parameter values and distributions to use in future dose calculations.

Appendix A describes the various assumptions that were applied to ensure that this methodology is internally consistent. Appendix B provides additional details of the development for select parameters, providing additional transparency and traceability. Appendix C provides biosphere dose conversion factors (BDCFs) that result from applying the dose methodology defined here to unit concentrations (i.e., 1.0 pCi/L for each radionuclide). Appendix D compares dose results from previous dose methodologies to this revised approach.

1.1 Human Receptor Definitions

The two hypothetical human dose receptors discussed in this report are the MOP and the IHI. These receptors were developed according to guidance provided in DOE Guide 435.1-1, Section IV.P.(2).

> *"[P]erformance measures ... shall be based on reasonable activities in the critical group of exposed individuals. Unless otherwise specified, the assumption of average living habits and exposure conditions in representative critical groups of individuals projected to receive the highest doses is appropriate."*

The guide defines the critical group as "the portion of the exposed population likely to receive the highest dose". For the purpose of this dose methodology, the critical group for the MOP shall be defined as typical persons who use water from a contaminated well (either along the 100-meter boundary of the source of the contamination or at the nearest downgradient stream). Similarly, the critical group for the IHI shall be defined typical persons who use water from a contaminated well is within the 100-meter boundary of the source of the contamination.

Additionally, DOE Guide 435.1-1 also indicates that performance assessments "shall use DOE-approved coefficients (dose conversion factors) for internal and external exposure of reference adults." The latest DOE-approved dose coefficients are found within the *DOE Standard: Derived Concentration Technical Standard*. [DOE-STD-1196-2011] This DOE technical standard further explains that the dose coefficients were developed based upon the concept of a "Reference Person" using age- and gender- dependent intake rates for ingestion of water and inhalation of air. Therefore, rather than assuming adult-specific values, the critical group shall be interpreted as being an age- and gender- weighted Reference Person.

The MOP and IHI are both assumed to be "typical" future persons, as defined by *Site Specific Reference Person Parameters and Derived Concentration Standards for the Savannah River Site*:

> *"The typical person is a hypothetical reference person that is typical of the entire population group and it is established at the 50th percentile (median) of the national data… The median (as opposed to the mean) is better suited for skewed distributions, which are typical for human intake rates, to derive at central tendency since it is much more robust and sensible."* [SRNL-STI-2013-00115]

Using median data is also consistent with the *DOE Standard: Derived Concentration Technical Standard* which used median data to derive the applicable dose coefficients. [DOE-STD-1196-2011]

Table 1.1-1 summarizes the definition of each human receptor.

Table 1.1-1: Definition of Human Receptors

Characteristic	MOP	IHI
Demographic of Receptor	Age- and Gender- Weighted Reference Person	
Location of Receptor	At the 100-meter boundary - OR - At the nearest downgradient stream	Within the 100-meter boundary
Behaviors of the Receptor	Typical (median) living habits	

1.2 Exposure Scenarios

For dose calculations, two MOP exposure scenarios are considered: (1) the MOP at the 100-Meter Well and (2) the MOP at the Stream. The MOP at the 100-Meter Well is a modeling scenario that assumes the MOP uses water from a well that has been drilled 100 meters away from the contaminated source. The MOP uses the contaminated water in a number of ways (e.g., as a drinking source, for showering, for irrigating crops, etc.). Section 3 provides the recommended dose methodology for calculating dose to the MOP at the 100-Meter Well.

The MOP at the Stream is a similar modeling scenario, however the contaminated water source is from a stream that is down-gradient from the contaminated source. Section 4 provides the recommended dose methodology for calculating dose to the MOP at the Stream.

The IHI is an assumed future person who lives at or very near the contaminated source and uses water from a well that has been drilled within the 100-meter boundary of the facility. For dose calculations, two IHI scenarios are considered: (1) the Acute IHI and (2) the Chronic IHI. The Acute IHI scenario assumes that the IHI receptor is the driller of the 1-meter well. The acute IHI receptor comes into direct contact with contaminated drill cuttings for a relatively short amount of time. Section 5 provides the recommended dose methodology for calculating dose to the Acute IHI.

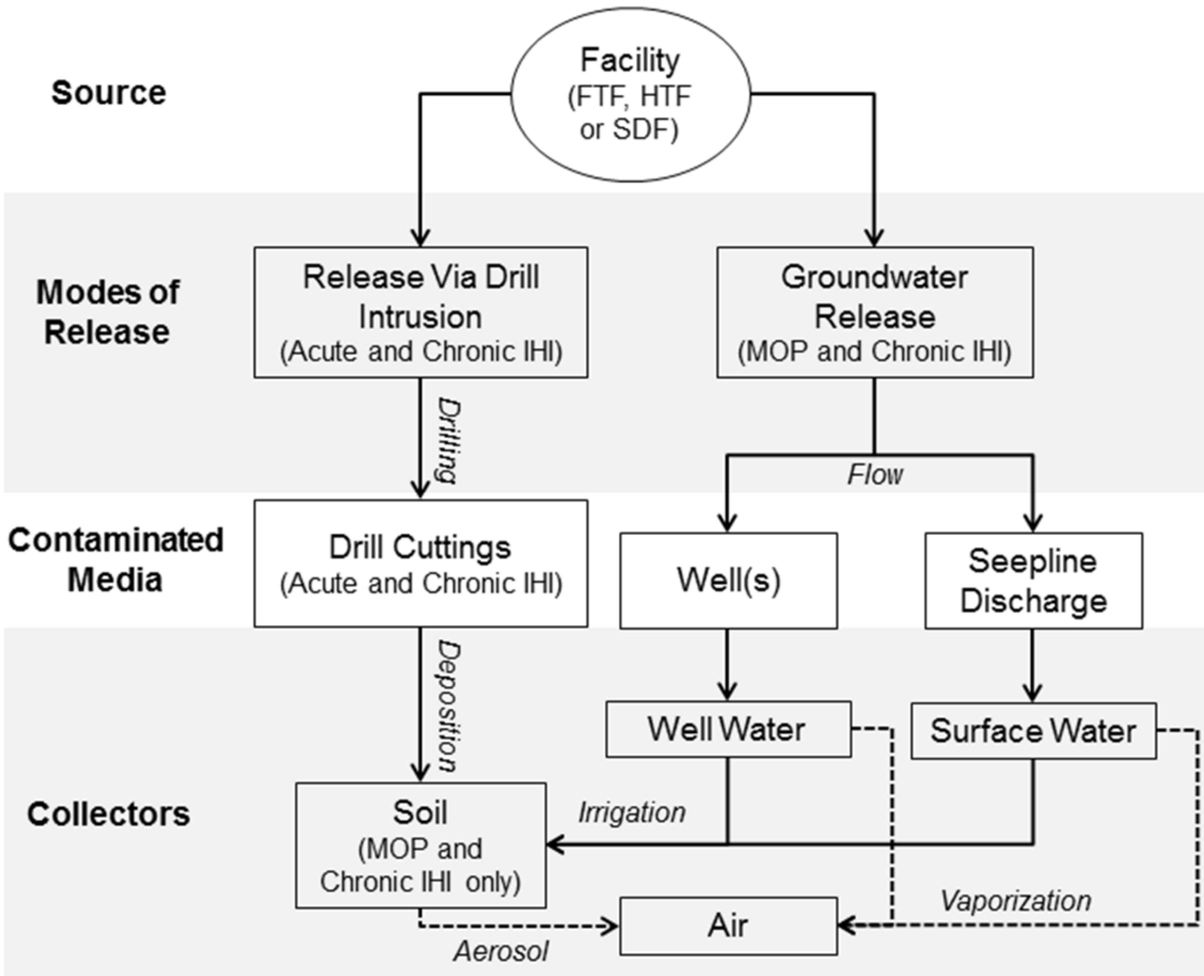
The Chronic IHI scenario is similar to the MOP scenarios but includes contributions from the contaminated drill cuttings as well as the higher concentrations of contaminants from the closer well. Section 6 provides the recommended dose methodology for calculating dose to the Chronic IHI.

Note that upon closure of liquid waste facilities, the stabilized contaminant materials will be protected by significant, long lasting materials which are clearly distinguishable from the surrounding soil and make drilling an improbable scenario based on regional drilling practices. Regional drilling conditions are such that a well driller would stop operations and move their drilling location upon encountering barriers, such as the closure cap erosion barrier, steel or concrete roof, or grout. As such, modeling scenarios which incorporate contaminant concentrations from drill cutting pulled directly from the waste form do not reflect expected future conditions but are provided as alternative scenarios used to inform decision-making.

1.3 Contaminant and Dose Process Overview

Figure 1-1 illustrates the process through which contaminants may be collected into the biosphere (i.e., received by the MOP or IHI receptors). Once the contaminated media interacts with the environmental collectors (i.e., soil, air, well water, and surface water), the radioactive material then becomes accessible for accumulation and uptake within the biosphere where it becomes a dose risk.

Figure 1-1: Contamination Process Overview



FTF = F-Tank Farm
HTF = H-Tank Farm
SDF = Saltstone Disposal Facility

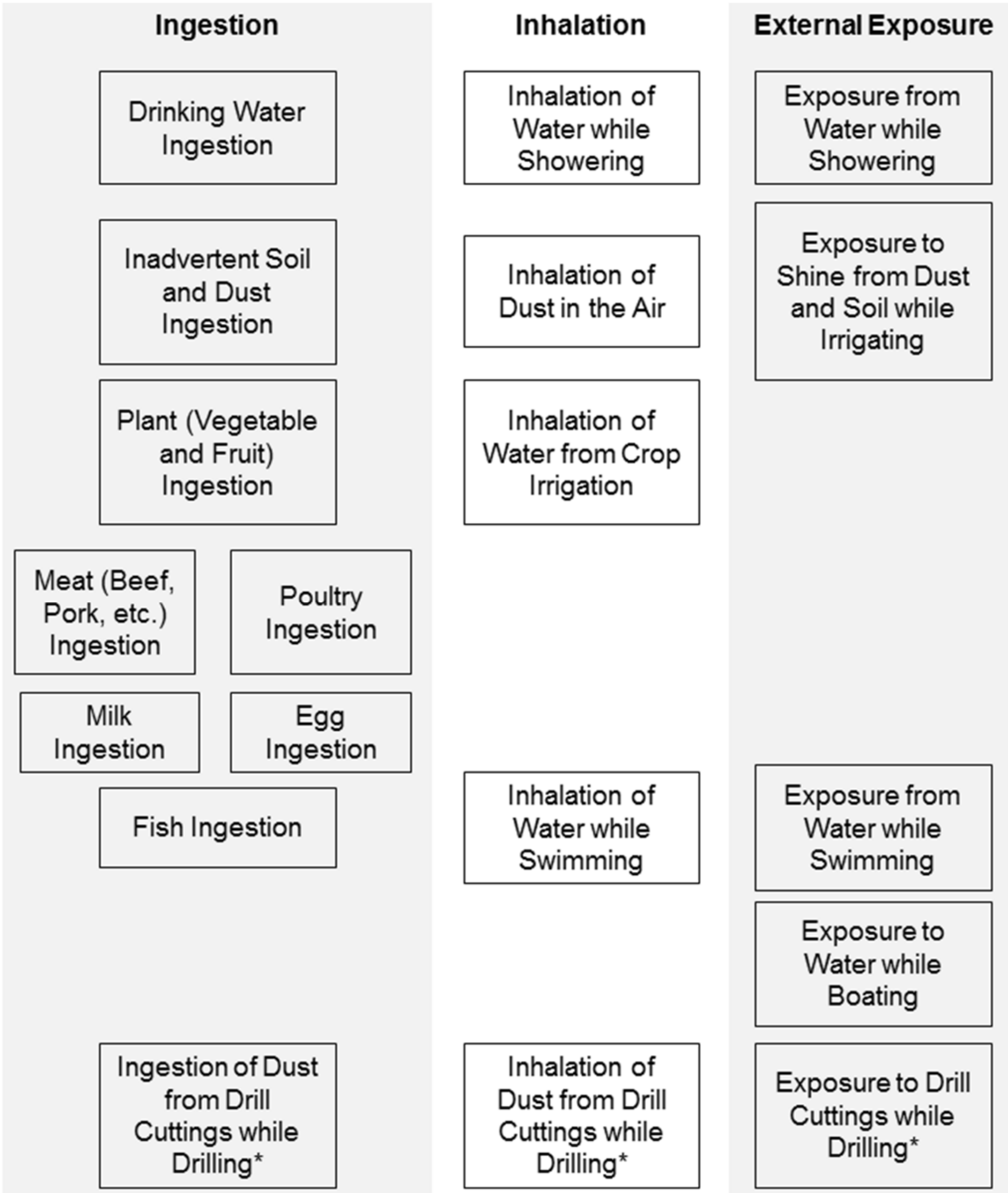
For the purposes of liquid waste performance assessments at the Savannah River Site, the MOP and IHI receptors are expected to receive dose from various dose pathways. At a high level, all the dose pathways fall into three categories: the ingestion dose pathway, the inhalation dose pathway, and the external exposure dose pathways. The total dose to the MOP or the IHI is the sum of the dose from each of these dose pathway categories.

The calculations herein define each of these pathways and provide calculations for determining dose impacts for specific pathways that provide input to the three dose pathway categories. Figure 1-2 illustrates the various pathways through which a human receptor receives a dose.

Sections 3 through 6 provide descriptions of how each of these pathways are applied for determining dose based on the exposure scenarios discussed in Section 1.2. Included in the discussion are details of which environmental collectors (i.e., soil, air, well water, and surface water) are used as inputs to each pathway.

Dose pathways that are not included are considered negligible or non-applicable. For example, the ingestion of contaminated grains and cereals is non-applicable because it is assumed, based on current land usage in the area, that only fruits and vegetables will be grown at the Savannah River Site.

Figure 1-2: Dose Pathway Overview



* Pathways related to drill cuttings only apply to IHI scenarios.

2.0 METHODOLOGY HISTORY AND APPROACH

The methodology described herein builds on the dose calculation methods applied within the current Liquid Waste PAs (as listed in Table 1.0-1). The equations are generally based on equations found in the Liquid Annual Dose to All Persons (LADTAP) model or in the PA for the Idaho National Engineering and Environmental Laboratory (INEEL) Tank Farm. [WSRC-STI-2006-00123, DOE/ID-10966] While these documents were used as guides for the formulas, ultimately the basis for all the formulas can be traced to Regulatory Guide 1.109.

The major differences in the methods described herein relative to the current Liquid Waste PAs are:

(1) Previous input parameters sometimes applied values that were specific to adults (or adult groups), rather than using the more appropriate age- and gender- weighted values as is consistent with the definition of the critical group (as given in Section 1.1);

(2) The vegetable ingestion pathway has been modified to include the ingestion of both fruit and vegetables and redefined as a “produce” or “plant” ingestion pathway;

(3) The poultry and egg ingestion pathways have been updated to conservatively include the uptake of soil with the fodder;

(4) For meat, milk, poultry, and egg ingestion pathways, the chronic IHI dose scenario has been updated to incorporate the effects of contaminants from drill cuttings being taken up by fodder that is then ingested by terrestrial livestock and poultry;

(5) The soil exposure and dust inhalation pathways for the chronic IHI dose scenario have been updated to incorporate the effects of contaminants from drill cuttings distributed into a local garden;

(6) A pathway for external water exposure while showering or bathing has been added.

(7) The leafy vegetable retention fraction for iodine was corrected (from 0.25 to 1.0) to reflect the footnote from Table 3-2 of the reference document. [WSRC-STI-2007-00004, Rev. 4]

(8) Recommendations for updated input parameter values are provided based on the recent *Exposure Factors Handbook* prepared by the U.S. Environmental Protection Agency (EPA) and information from related literature reviews. [EPA-600-R-090-052F]

The differences identified above as items 1 through 7 are generally expected to increase dose results; however the new recommended parameter values (item 8) are generally expected to reduce the dose results. Appendices C and D incorporate all items (1 through 8), applying the dose methodology described within this report to the contaminant concentrations from current Liquid Waste PAs to assess the overall impact of these changes.

2.1 Guidance for Reading the Formulas

Due to the large number of equations provided within this report, Table 2.1-1 is provided as a primer to introduce readers to some of the naming conventions used within the formulas. This table doesn’t include all of the formula nomenclature used within this report, as each equation

provides an adequate description of each parameter. Instead, this table provides examples of the more commonly used terms as an introduction.

Table 2.1-1: Formula Nomenclature Overview

Formula Symbol (example)	**Description**
C_{SL}	*C* denotes concentration. Concentrations are expressed as pCi/L or kg/L. The subscript following the *C* provides additional information to the reader about which concentration is being expressed in the formula. In this example, the concentration in stream water at the seepline (SL) is shown.
$D_{MOP,100}$	*D* denotes dose. Typically doses shall be expressed as mrem/yr, except for acute doses, which are expressed as mrem. The subscript following the *D* provides additional information to the reader about what type of dose pathway is being expressed in the formula. In this example, the total dose to the MOP receptor at the 100-meter well is shown.
DCF_{ing}	*DCF* denotes a dose conversion factor (DCF). DCFs are used to convert activities to dose and are expressed as mrem/pCi. Because the human body responds to different radionuclides in different ways, based on the exposure pathway (i.e., ingestion, inhalation, and external exposure), DCFs are pathway-specific. This is the DCF for human ingestion.
EDF_{H2Oing}	*EDF* denotes the effective dose factor (EDF). EDFs are typically expressed as (L×mrem)/(pCi×yr) such that multiplying the EDF by the concentration gives the dose. For acute doses, the EDFs are expressed as (L×mrem)/(pCi). This example expressed the EDF for water ingestion.
F_{wash}	*F* denotes a fraction. Fractions are unitless values from 0 to 1. In dose formulas fractions are used to modify the equations based on the influences of various factors. The example shown here is used to modify the produce dose by applying the fraction of material deposited on leaves that is retained after washing.
$Q_{fod,MEAT}$	*Q* denotes animal consumption (or uptake) of water, fodder, or soil. Typically, this is expressed as L/d or kg/d. This example shows the consumption of fodder by sources of meat (i.e., terrestrial livestock meat such as beef, pork, etc.).
TC_{EGG}	*TC* denotes transfer coefficients (TC) or transfer factors. These are expressed as d/kg or d/L. Transfer coefficients represent the uptake of contaminants through various pathways. These are element-specific values. This example shows the transfer coefficient for eggs, which is used to convert consumed (or uptake) mass into a unitless multiplier.
U_{SOIL}	*U* denotes human consumption or uptake and is expressed as this is expressed as L/d or kg/d. This example is used to express the inadvertent consumption of soil and dust used in the ingestion pathway dose equations.

3.0 MOP AT THE 100-METER WELL DOSE PATHWAYS

The following MOP exposure pathways were used in calculating the dose to the MOP receptor with 100-meter well water as a primary water source. The stream is a secondary water source for the pathways involving swimming, boating, and fish ingestion. All transfer times are assumed to be negligible due to the long-term analysis of the PAs. Unit conversions are not explicitly stated in the equations, but are implied.

The dose to the MOP at the 100-meter well is determined according to Equation 3-1:

$$D_{MOP,100} = D_{MOP,100,ing} + D_{MOP,100,\exp} + D_{MOP,100,inh} \quad \text{(Eq. 3-1)}$$

where:

$D_{MOP,100}$ = total dose to the MOP at the 100-meter well (mrem/yr)

$D_{MOP,100,ing}$ = dose to the MOP at the 100-meter well (mrem/yr) due to ingestion (see Equation 3.1-1)

$D_{MOP,100,\exp}$ = dose to the MOP at the 100-meter well (mrem/yr) due to exposure (see Equation 3.2-1)

$D_{MOP,100,inh}$ = dose to the MOP at the 100-meter well (mrem/yr) due to inhalation (see Equation 3.3-1)

3.1 MOP at the 100-Meter Well, Ingestion Dose Pathways

The following text defines the parameter $D_{MOP,100,ing}$ from Equation 3-1. The ingestion dose to the MOP at the 100-meter well is determined according to Equation 3.1-1:

$$\begin{aligned} D_{MOP,100,ing} &= D_{MOP,100,H2Oing} + D_{MOP,100,SOILing} + D_{MOP,100,PLANTing} \\ &+ D_{MOP,100,MEATing} + D_{MOP,100,MILKing} + D_{MOP,100,POULTRYing} \\ &+ D_{MOP,100,EGGing} + D_{SL,FISHing} \end{aligned} \quad \text{(Eq. 3.1-1)}$$

where:

$D_{MOP,100,ing}$ = dose to the MOP at the 100-meter well (mrem/yr) due to ingestion

$D_{MOP,100,H2Oing}$ = dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of water from the 100-meter well

$D_{MOP,100,SOILing}$ = dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of soil that has been irrigated with water from the 100-meter well

$D_{MOP,100,PLANTing}$ = dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of produce (both fruits and vegetables) irrigated from the 100-meter well water

$D_{MOP,100,MEATing}$ = dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of meat (i.e., terrestrial livestock meat such as beef, pork, veal, etc.) that eats fodder watered by

and drinks water from the 100-meter well

$D_{MOP,100,MILKing}$ = dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of milk that comes from livestock that eats fodder watered by and drinks water from the 100-meter well

$D_{MOP,100,POULTRYing}$ = dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of poultry (including chicken, turkey, etc.) that eats fodder watered by and drinks water from the 100-meter well

$D_{MOP,100,EGGing}$ = dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of eggs that come from poultry that eats fodder watered by and drinks water from the 100-meter well

$D_{SL,FISHing}$ = dose (mrem/yr) due to ingestion of fish that came from stream water near the contaminated SL

Note that the equations described below conservatively assume instant transport and preparation of foods. For example, rather than modeling a lag period of a few days from the time that meat is slaughtered until it is consumed, the meat is consumed instantly. Given the relatively long durations considered for Liquid Waste PA modeling, this conservative assumption is expected to have a negligible impact on results.

3.1.1 Ingestion of Water (MOP at the 100-Meter Well)

The exposure pathway for water ingestion assumes the MOP receptor uses a well as a drinking water source that is located 100 meters from the contaminated source. The incidental ingestion of water from showering and during recreational activities is assumed negligible when compared to ingestion of drinking water. The dose from consumption of drinking water shall be calculated according to Equation 3.1-2:

$$D_{MOP,100,H2Oing} = C_{GW,100} \times EDF_{H2Oing} \quad \text{(Eq. 3.1-2)}$$

where:

$D_{MOP,100,H2Oing}$ = dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of water from the 100-meter well

$C_{GW,100}$ = radionuclide concentration in groundwater from the 100-meter well (pCi/L), as determined from an appropriate contaminant transport model

EDF_{H2Oing} = effective dose factor for ingestion of contaminated groundwater (L×mrem)/(pCi×yr), defined in Equation 3.1-2a, below

The EDF for ingestion of drinking water shall be calculated as:

$$EDF_{H2Oing} = U_{H2O} \times DCF_{ing} \times F_{local,H2O} \quad \text{(Eq. 3.1-2a)}$$

where:

EDF_{H2Oing}	=	effective dose factor for ingestion of contaminated groundwater (L×mrem)/(pCi×yr)
U_{H2O}	=	human consumption rate of water (L/yr), Table 7.2-1
DCF_{ing}	=	dose conversion factor for ingestion of contaminated groundwater (mrem/pCi), Table 7.1-1
$F_{local,H2O}$	=	fraction of consumed water that comes from the local water source (unitless), Table 7.6-1

3.1.2 Ingestion of Soil (MOP at the 100-Meter Well)

The soil ingestion pathway assumes the soil is irrigated with groundwater from the 100-meter well and the MOP receptor in turn consumes the contaminated soil. This formula was derived following the approach of the previous pathway calculations. A soil buildup factor was applied to account for the buildup of radionuclide concentration in the soil from successive years of irrigation. The radionuclide concentration in the soil and the dose is calculated using the following formula:

$$D_{MOP,100,SOILing} = C_{GW,100} \times EDF_{SOILing} \qquad \text{(Eq. 3.1-3)}$$

where:

$D_{MOP,100,SOILing}$	=	dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of soil that has been irrigated with water from the 100-meter well
$C_{GW,100}$	=	radionuclide concentration in groundwater from the 100-meter well (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{SOILing}$	=	effective dose factor for ingestion of soil contaminated by groundwater (L×mrem)/(pCi×yr), defined in Equation 3.1-3a, below

The EDF for soil ingestion shall be calculated as:

$$EDF_{SOILing} = SOIL \times I_{RF} \times DCF_{ing} \times U_{SOIL} \qquad \text{(Eq. 3.1-3a)}$$

where:

$EDF_{SOILing}$	=	effective dose factor for ingestion of soil contaminated by groundwater (L×mrem)/(pCi×yr)
$SOIL$	=	radionuclide deposition and buildup rate in the soil ((m^2×yr)/kg) as defined by equations 3.1-3b and 3.1-3c, below
I_{RF}	=	functional irrigation rate (m/yr) as defined by Equation 3.1-3d, below
DCF_{ing}	=	dose conversion factor for ingestion (mrem/pCi), Table 7.1-1

U_{SOIL} = human consumption rate of soil (kg/yr), Table 7.2-1

The $SOIL$ parameter from Equation 3.1-3a (above) is defined as follows:

$$SOIL = \frac{\left(1 - e^{-(\lambda_i + \lambda_L)t_b}\right)}{\rho_{ss} \times \left(\lambda_i + \lambda_L\right)} \qquad \text{(Eq. 3.1-3b)}$$

where:

$SOIL$ = radionuclide deposition and buildup rate in the soil ((m^2×yr)/kg)

λ_i = radiological decay constant (1/yr) [ln(2)/half-life of radionuclide *i*]

λ_L = leachate impact on buildup of radionuclides in soil (1/yr), as described in Equation 3.1-3c

t_b = buildup time of radionuclides in soil (yr), Table 7.5-1

ρ_{ss} = surface soil density (kg/m^2), Table 7.5-1

Equation 3.1-3b uses:

$$\lambda_L = \frac{PR + I_{RF} - ER}{d_{till} \times \left(MC_{soil} \times \rho_S \times Kd_i\right)} \qquad \text{(Eq. 3.1-3c)}$$

where:

λ_L = leachate impact on buildup of radionuclides in soil (1/yr)

PR = precipitation rate (m/yr), Table 7.5-1

I_{RF} = functional irrigation rate (m/yr) as defined by Equation 3.1-3d, below

ER = evapotranspiration rate (m/yr), Table 7.5-1

d_{till} = depth of tilling for agriculture or gardening (m), Table 7.5-2

MC_{soil} = soil moisture content (unitless), Table 7.5-1

ρ_S = dry bulk density of soil (kg/m^3), Table 7.5-1

Kd_i = soil distribution coefficients for radionuclide *i* (L/kg), Table 7.7-1

The functional irrigation rate I_{RF} from Equations 3.1-3a and 3.1-3c is defined as:

$$I_{RF} = \left(IR \times F_{irr}\right) \quad \text{(Eq. 3.1-3d)}$$

where:

I_{RF}	=	functional irrigation rate (m/yr)
IR	=	irrigation rate (m/yr), Table 7.5-1
F_{irr}	=	fraction of the time produce is irrigated (unitless), Table 7.5-2

Note that the soil buildup equation (Eq. 3.1-3b) accounts for radiological decay (with the radiological decay constant: λ_i). However, as a modeling simplification this equation does not account for radiological ingrowthnor the removal of mass due to weathering.

3.1.3 Ingestion of Produce (MOP at the 100-Meter Well)

The dose to the MOP receptor from ingestion of contaminated produce (including leafy vegetables, other vegetables, and fruit) is calculated assuming two contamination exposure pathways: (1) direct deposition of contaminated irrigation water on plants and (2) root uptake of contaminated irrigation water in soil. The irrigation water is from the 100-meter well. The dose is calculated using Equation 3.1-4:

$$D_{MOP,100,PLANTing} = C_{GW,100} \times EDF_{PLANTing} \times F_{local,PLANT} \quad \text{(Eq. 3.1-4)}$$

where:

$D_{MOP,100,PLANTing}$	=	dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of produce (both fruits and vegetables) irrigated from the 100-meter well water
$C_{GW,100}$	=	radionuclide concentration in groundwater from the 100-meter well (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{PLANTing}$	=	effective dose factor for ingestion of plants contaminated by groundwater (L×mrem)/(pCi×yr), defined in Equation 3.1-4a, below
$F_{local,PLANT}$	=	fraction of consumed produce grown locally (unitless), Table 7.6-1

The EDF for MOP plant ingestion shall be calculated as:

$$EDF_{PLANTing} = I_{RF} \times P_{in} \times U_P \times DCF_{ing} \quad \text{(Eq. 3.1-4a)}$$

where:

$EDF_{PLANTing}$	=	effective dose factor for ingestion of plants contaminated by groundwater (L×mrem)/(pCi×yr)
I_{RF}	=	functional irrigation rate (m/yr) as defined by Equation 3.1-3d, above

P_{in} = radionuclide uptake, deposition and retention rate in plants ((m^2×yr)/kg), as defined in Equation 3.1-4b, below

U_P = human consumption rate of plants or produce (kg/yr), Table 7.2-1

DCF_{ing} = dose conversion factor for ingestion (mrem/pCi), Table 7.1-1

The plant intake parameter P_{in} from Equation 3.1-4a is defined as:

$$P_{in} = (LEAF \times F_L \times F_{wash}) + ROOT \quad \text{(Eq. 3.1-4b)}$$

where:

P_{in} = radionuclide uptake, deposition and retention rate in plants ((m^2×yr)/kg)

$LEAF$ = radionuclide deposition and retention rate on produce leaves ((m^2×yr)/kg), as defined in Equation 3.1-4c, below

F_{leaf} = fraction of produce that is leafy (unitless), Table 7.5-2

F_{wash} = fraction of material deposited on leaves that is retained after washing (unitless), Table 7.5-2

$ROOT$ = radionuclide uptake through produce roots ((m^2×yr)/kg), as defined in Equation 3.1-4d, below

The $LEAF$ and $ROOT$ parameters from Equation 3.1-4b are defined by the following equations, where:

$$LEAF = \frac{F_r \times \left(1 - e^{-\lambda_e t_{irr}}\right)}{Y_g \times \lambda_e} \quad \text{(Eq. 3.1-4c)}$$

where:

$LEAF$ = radionuclide deposition and retention rate on the produce leaves ((m^2×yr)/kg)

F_r = fraction of material deposited on leaves that is retained (unitless), Table 7.5-2

λ_e = weathering and radiological decay constant (1/yr), as defined in Equation 3.1-4e, below

t_{irr} = time produce is exposed to irrigation (yr), Table 7.5-2

Y_g = crop and garden production yield (kg/m^2), Table 7.5-2

and:

$$ROOT = \left(F_{leaf} \times R_{StoV} \times SOIL\right) + \left(F_{nonleaf} \times R_{StoV} \times SOIL\right) \quad \text{(Eq. 3.1-4d)}$$

where:

F_{leaf}	=	fraction of produce that is leafy, Table 7.5-2
$F_{nonleaf}$	=	fraction of produce that is not leafy (1.0 – F_{leaf})
$ROOT$	=	radionuclide uptake through produce roots ((m^2×yr)/kg)
R_{StoV}	=	soil to vegetation ratio (unitless), Table 7.3-1
$SOIL$	=	radionuclide deposition and ((m^2×yr)/kg), as defined in Equation 3.1-3b, above

Finally, the weathering and radiological decay parameter λ_e from Equation 3.1-4c is defined as:

$$\lambda_e = \lambda_i + \lambda_w \quad \text{(Eq. 3.1-4e)}$$

where:

λ_e	=	weathering and radiological decay constant (1/yr)
λ_i	=	radiological decay constant (1/yr) [ln(2)/half-life of radionuclide *i*], Table 7.5-1
λ_w	=	weathering decay constant (1/yr), Table 7.5-1

3.1.4 Ingestion of Meat (MOP at the 100-Meter Well)

The meat ingestion pathway assumes that terrestrial livestock drinks contaminated stock water and consumes fodder irrigated with contaminated water. The stock water and irrigation water is from the 100-meter well. The fodder is contaminated from direct deposition of contaminated irrigation water on plants and from deposition of contaminated irrigation water in soil followed by root uptake by plants. The buildup of radionuclide concentration in the soil from successive years of irrigation is accounted for. The radionuclide concentration in fodder from deposition and root uptake is calculated as well.

For the purpose of this calculation, meat (or terrestrial livestock) includes all meat that is not classified as poultry or fish. This includes beef, pork, veal, and other game.

After livestock consumes contaminated water and fodder, the MOP receptor consumes the contaminated meat. The dose from ingesting contaminated meat is calculated using the following formula:

$$D_{MOP,100,MEATing} = C_{GW,100} \times EDF_{MEATing} \times F_{local,MEAT} \quad \text{(Eq. 3.1-5)}$$

where:

$D_{MOP,100,MEATing}$	=	dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of meat (i.e., terrestrial livestock meat such as beef, pork, veal, etc.) that eats fodder watered by and drinks water from the 100-meter well
$C_{GW,100}$	=	radionuclide concentration in groundwater from the 100-meter well (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{MEATing}$	=	effective dose factor for ingestion of terrestrial livestock meat contaminated by groundwater (L×mrem)/(pCi×yr), as defined in Equation 3.1-5a, below
$F_{local,MEAT}$	=	fraction of terrestrial livestock raised locally (unitless), Table 7.6-1

The EDF for meat ingestion shall be calculated as:

$$EDF_{MEATing} = \left(Q_{H2O,MEAT} + \left(Fod \times Q_{fod,MEAT} \times F_{fod,MEAT}\right)\right) \times TC_{MEAT} \times U_{MEAT} \times DCF_{ing} \quad \text{(Eq. 3.1-5a)}$$

where:

$EDF_{MEATing}$	=	effective dose factor for ingestion of terrestrial livestock meat contaminated by groundwater (L×mrem)/(pCi×yr)
$Q_{H2O,MEAT}$	=	consumption rate of water by terrestrial livestock (L/yr), Table 7.2-2
Fod	=	terrestrial livestock or poultry intake of contaminated feed/fodder (m^3/kg), as defined in Equation 3.1-5b, below
$Q_{fod,MEAT}$	=	consumption rate of fodder by terrestrial livestock (kg/yr), Table 7.2-2
$F_{fod,MEAT}$	=	fraction of terrestrial livestock intake from field/pasture that is irrigated with water from the contaminated well (unitless), Table 7.2-3
TC_{MEAT}	=	transfer coefficient for terrestrial livestock (including beef, pork, veal, etc.) (yr/kg), Table 7.3-2
U_{MEAT}	=	human consumption rate of meat (i.e., terrestrial livestock meat such as beef, pork, veal, etc.) (kg/yr), Table 7.2-1
DCF_{ing}	=	dose conversion factor for ingestion (mrem/pCi), Table 7.1-1

The Fod parameter from Equation 3.1-5a is defined by Equation 3.1-5b. This equation also uses equations 3.1-3d and 3.1-4b, as follows:

$$Fod = I_{RF} \times P_{in} \qquad \text{(Eq. 3.1-5b)}$$

where:

Fod	=	terrestrial livestock or poultry intake of contaminated feed/fodder (m^3/kg)
I_{RF}	=	functional irrigation rate (m/yr) as defined by Equation 3.1-3d, above
P_{in}	=	radionuclide uptake and deposition and retention rate in plants ((m^2×yr)/kg), as defined in Equation 3.1-4b, above

3.1.5 Ingestion of Milk (MOP at the 100-Meter Well)

After milk cows (or other milk-producing livestock) consume contaminated water and fodder, the MOP receptor consumes the contaminated milk. The dose from ingestion of contaminated milk is calculated using the following formula:

$$D_{MOP,100,MILKing} = C_{GW,100} \times EDF_{MILKing} \times F_{local,MILK} \qquad \text{(Eq. 3.1-6)}$$

where:

$D_{MOP,100,MILKing}$	=	dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of milk that comes from livestock that eats fodder watered by and drinks water from the 100-meter well
$C_{GW,100}$	=	radionuclide concentration in groundwater from the 100-meter well (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{MILKing}$	=	effective dose factor for ingestion of milk contaminated by groundwater (L×mrem)/(pCi×yr), as defined in Equation 3.1-6a, below
$F_{local,MILK}$	=	fraction of milk-producing livestock raised locally (unitless), Table 7.6-1

The EDF for milk ingestion shall be calculated as:

$$EDF_{MILKing} = \left(Q_{H2O,MILK} + \left(Fod \times Q_{fod,MILK} \times F_{fod,MILK}\right)\right) \times TC_{MILK} \times \left(\frac{U_{MILK}}{\rho_{milk}}\right) \times DCF_{ing} \qquad \text{(Eq. 3.1-6a)}$$

where:

$EDF_{MILKing}$	=	effective dose factor for ingestion of milk contaminated by groundwater (L×mrem)/(pCi×yr)

$Q_{H2O,MILK}$ = consumption rate of water by milk producing livestock (L/yr), Table 7.2-2

Fod = terrestrial livestock or poultry intake of contaminated feed/fodder (m^3/kg), as defined in Equation 3.1-5b, above

$Q_{fod,MILK}$ = consumption rate of fodder by milk producing livestock (kg/yr), Table 7.2-2

$F_{fod,MILK}$ = fraction of milk-producing livestock fodder consumption from field/pasture that is irrigated with water from the contaminated well (unitless), Table 7.2-3

TC_{MILK} = Transfer coefficient for milk (yr/L), Table 7.3-3

U_{MILK} = human consumption rate of milk (kg/yr), Table 7.2-1

ρ_{milk} = milk density (kg/L) , Table 7.2-1 (table note)

DCF_{ing} = dose conversion factor for ingestion (mrem/pCi), Table 7.1-1

3.1.6 Ingestion of Poultry (MOP at the 100-Meter Well)

The poultry and egg exposure pathways assume poultry and egg-producing livestock drink contaminated stock water and consume fodder irrigated with contaminated water. The stock water and irrigation water is from the 100-meter well. The fodder is contaminated from direct deposition of contaminated irrigation water on plants and from deposition of contaminated irrigation water in soil followed by root uptake by plants. For conservatism, it is also assumed that poultry directly ingest contaminated soil in addition to the stock water and fodder. The dose from ingestion of contaminated poultry is calculated using the following formula:

$$D_{MOP,100,POULTRYing} = C_{GW,100} \times EDF_{POULTRYing} \times F_{local,POULTRY} \qquad \text{(Eq. 3.1-7)}$$

where:

$D_{MOP,100,POULTRYing}$ = dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of poultry (including chicken, turkey, etc.) that eats fodder watered by and drinks water from the 100-meter well

$C_{GW,100}$ = radionuclide concentration in groundwater from the 100-meter well (pCi/L), as determined from an appropriate contaminant transport model

$EDF_{POULTRYing}$ = effective dose factor for ingestion of poultry contaminated by groundwater (L×mrem)/(pCi×yr), as defined in Equation 3.1-7a, below

$F_{local,POULTRY}$ = fraction of poultry raised locally (unitless), Table 7.6-1

The EDF for poultry ingestion shall be calculated as:

$$EDF_{POULTRYing} = \begin{pmatrix} Q_{H2O,POULTRY} + \left(Fod \times Q_{fod,POULTRY} \times F_{fod,POULTRY}\right) \\ + \left(SOIL \times I_{RF} \times Q_{SOIL,POULTRY} \times F_{SOIL,POULTRY}\right) \end{pmatrix} \times TC_{POULTRY} \times U_{POULTRY} \times DCF_{ing} \quad \text{(Eq. 3.1-7a)}$$

where:

$EDF_{POULTRYing}$	=	effective dose factor for ingestion of poultry contaminated by groundwater (L×mrem)/(pCi×yr)
$Q_{H2O,POULTRY}$	=	consumption rate of water by poultry (L/yr), Table 7.2-2
Fod	=	terrestrial livestock or poultry intake of contaminated feed/fodder (m^3/kg), as defined in Equation 3.1-5b, above
$Q_{fod,POULTRY}$	=	consumption rate of fodder consumed by poultry (kg/yr), Table 7.2-2
$F_{fod,POULTRY}$	=	fraction of poultry fodder consumption from field/pasture that is irrigated with water from the contaminated well (unitless), Table 7.2-3
$SOIL$	=	radionuclide deposition and buildup rate in the soil ((m^2×yr)/kg) as defined by Equation 3.1-3b
I_{RF}	=	functional irrigation rate (m/yr) as defined by Equation 3.1-3d, above
$Q_{SOIL,POULTRY}$	=	consumption rate of soil by poultry (kg/yr), Table 7.2-2
$F_{SOIL,POULTRY}$	=	fraction of poultry soil intake from field/pasture that is irrigated with water from the contaminated well (unitless), Table 7.2-3
$TC_{POULTRY}$	=	transfer coefficient for poultry (yr/kg), Table 7.3-4
$U_{POULTRY}$	=	human consumption rate of poultry (kg/yr), Table 7.2-1
DCF_{ing}	=	dose conversion factor for ingestion (mrem/pCi), Table 7.1-1

3.1.7 Ingestion of Egg (MOP at the 100-Meter Well)

After egg-producing livestock consumes the contaminated water and fodder, the MOP consumes the contaminated eggs. The dose from ingestion of contaminated eggs is calculated using the following formula:

$$D_{MOP,100,EGGing} = C_{GW,100} \times EDF_{EGGing} \times F_{local,EGG} \quad \text{(Eq. 3.1-8)}$$

where:

$D_{MOP,100,EGGing}$	=	dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of eggs that come from poultry that eats fodder watered by and drinks water from the 100-meter well
$C_{GW,100}$	=	radionuclide concentration in groundwater from the 100-meter well (pCi/L), as determined from an appropriate contaminant transport model
EDF_{EGGing}	=	effective dose factor for ingestion of eggs contaminated by groundwater (L×mrem)/(pCi×yr), as defined in Equation 3.1-8a, below
$F_{local,EGG}$	=	fraction of eggs raised locally (unitless), Table 7.6-1

The EDF for egg ingestion shall be calculated as:

$$EDF_{EGGing} = \begin{pmatrix} Q_{H2O,EGG} + \left(Fod \times Q_{fod,EGG} \times F_{fod,EGG}\right) \\ + \left(SOIL \times I_{RF} \times Q_{SOIL,EGG} \times F_{SOIL,EGG}\right) \end{pmatrix} \times TC_{EGG} \times U_{EGG} \times DCF_{ing} \qquad \text{(Eq. 3.1-8a)}$$

where:

EDF_{EGGing}	=	effective dose factor for ingestion of eggs contaminated by groundwater (L×mrem)/(pCi×yr)
$Q_{H2O,EGG}$	=	consumption rate of water by eggs (L/yr), Table 7.2-2
Fod	=	livestock and poultry intake of contaminated feed/fodder (m^3/kg), as defined in Equation 3.1-5b, above
$Q_{fod,EGG}$	=	consumption rate of fodder consumed by eggs (kg/yr), Table 7.2-2
$F_{fod,EGG}$	=	fraction of egg intake from field/pasture that is irrigated with from the contaminated well (unitless), Table 7.2-3
$SOIL$	=	radionuclide deposition and buildup rate in the soil ((m^2×yr)/kg) as defined by Equation 3.1-3b
I_{RF}	=	functional irrigation rate (m/yr) as defined by Equation 3.1-3d, above
$Q_{SOIL,EGG}$	=	consumption rate of soil by eggs (kg/yr), Table 7.2-2
$F_{SOIL,EGG}$	=	fraction of egg soil intake from field/pasture that is irrigated with from the contaminated well (unitless), Table 7.2-3
TC_{EGG}	=	transfer coefficient for eggs (yr/kg), Table 7.3-5
U_{EGG}	=	human consumption rate of eggs (kg/yr), Table 7.2-1

DCF_{ing} = dose conversion factor for ingestion (mrem/pCi), Table 7.1-1

3.1.8 Ingestion of Fish

The fish ingestion route assumes fish are caught from a contaminated stream at the point of highest concentration, and the MOP receptor in turn consumes the contaminated fish. The dose from consumption of fish shall be calculated according to Equation 3.1-9:

$$D_{SL,FISHing} = C_{SL} \times EDF_{FISHing} \times F_{local,FISH} \qquad \text{(Eq. 3.1-9)}$$

where:

$D_{SL,FISHing}$ = dose to (mrem/yr) due to ingestion of fish that came from stream water near the contaminated SL

C_{SL} = radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model

$EDF_{FISHing}$ = effective dose factor for fish ingestion (L×mrem)/(pCi×yr), as defined in Equation 3.1-9a, below

$F_{local,FISH}$ = fraction of consumed fish that are fished locally (unitless), Table 7.6-1

The EDF for fish ingestion shall be calculated as:

$$EDF_{FISHing} = \left(TC_{FISH} \times U_{FISH} \times DCF_{ing}\right) \qquad \text{(Eq. 3.1-9a)}$$

where:

$EDF_{FISHing}$ = effective dose factor for fish ingestion (L×mrem)/(pCi×yr)

TC_{FISH} = Transfer coefficient (or bioaccumulation factor) for fish (L/kg), Table 7.3-6

U_{FISH} = human consumption rate of fish (kg/yr), Table 7.2-1

DCF_{ing} = dose conversion factor for ingestion (mrem/pCi), Table 7.1-1

3.2 MOP at the 100-Meter Well, Direct Exposure Dose Pathways

The following text defines the parameter $D_{MOP,100,\exp}$ from Equation 3-1. The direct exposure dose to the MOP at the 100-meter well is determined according to Equation 3.2-1:

$$D_{MOP,100,\exp} = D_{MOP,100,SOIL\exp} + D_{MOP,100,SHOWER,\exp} + D_{SL,SWIM\exp} + D_{SL,BOAT\exp} \qquad \text{(Eq. 3.2-1)}$$

where:

$D_{MOP,100,\exp}$ = dose to the MOP at the 100-meter well (mrem/yr) due to exposure

$D_{MOP,100,SOIL\exp}$ = dose to the MOP at the 100-meter well (mrem/yr) due to direct exposure to soil irrigated from the 100-meter well

$D_{MOP,100,SHOWER,\exp}$ = dose to the MOP at the 100-meter well (mrem/yr) due to direct exposure while showering or bathing in water from the 100-meter well

$D_{SL,SWIM\exp}$ = dose (mrem/yr) due to direct exposure from swimming in stream water at the contaminated SL

$D_{SL,BOAT\exp}$ = dose (mrem/yr) due to direct exposure from boating in stream water at the contaminated SL

Note that direct exposure from fishing at the shoreline of a contaminated stream is considered negligible relative to the other exposure pathways and is not included in this methodology.

3.2.1 Direct Exposure from Irrigated Soil (MOP at the 100-Meter Well)

The exposure pathway from direct contact with contaminated soil assumes the soil is irrigated with groundwater from the 100-meter well and the MOP receptor in turn is exposed during time spent caring for a garden. The radionuclide concentration in the soil and the exposure dose is calculated using the following formula:

$$D_{MOP,100,SOIL\exp} = C_{GW,100} \times EDF_{SOIL\exp} \qquad \text{(Eq. 3.2-2)}$$

where:

$D_{MOP,100,SOIL\exp}$ = dose to the MOP at the 100-meter well (mrem/yr) due to direct exposure to soil irrigated from the 100-meter well

$C_{GW,100}$ = radionuclide concentration in groundwater from the 100-meter well (pCi/L), as determined from an appropriate contaminant transport model

$EDF_{SOIL\exp}$ = effective dose factor for external exposure to soil (L×mrem)/(pCi×yr), as defined in Equation 3.2-2a, below

The EDF for external exposure to soil shall be calculated as:

$$EDF_{SOIL\exp} = SOIL \times I_{RF} \times DCF_{\exp} \times F_{t,g} \times \rho_S \qquad \text{(Eq. 3.2-2a)}$$

where:

$EDF_{SOIL\exp}$ = effective dose factor for external exposure to soil (L×mrem)/(pCi×yr)

$SOIL$ = radionuclide deposition and buildup rate in the soil ((m^2×yr)/kg) as defined by Equation 3.1-3b

I_{RF}	=	functional irrigation rate (m/yr) as defined by Equation 3.1-3d, above
$DCF_{\exp}$	=	dose conversion factor for external exposure (m^3×mrem)/(pCi×yr) Table 7.1-1
$F_{t,g}$	=	fraction of the time the MOP spends in the contaminated garden (unitless), Table 7.4-1
ρ_S	=	dry bulk density of soil (kg/m^3), Table 7.5-1

3.2.2 Direct Exposure from Showering (MOP at the 100-Meter Well)

The direct contact exposure pathway from showering and bathing assumes the MOP receptor receives dose from washing in water from the 100-meter well. The dose is calculated using the following formula:

$$D_{MOP,100,SHOWER,\exp} = C_{GW,100} \times EDF_{SHOWER,\exp} \quad \text{(Eq. 3.2-3)}$$

where:

$D_{MOP,100,SHOWER,\exp}$	=	dose to the MOP at the 100-meter well (mrem/yr) due to direct exposure while showering or bathing in water from the 100-meter well
$C_{GW,100}$	=	radionuclide concentration in groundwater from the 100-meter well (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{SHOWER,\exp}$	=	effective dose factor for external exposure to water while showering or bathing (L×mrem)/(pCi×yr), as defined in Equation 3.2-3a, below

The EDF for external exposure to water while showering or bathing shall be calculated as:

$$EDF_{SHOWER,\exp} = F_{t,SHOWER} \times GF_{SHOWER} \times DCF_{imm} \quad \text{(Eq. 3.2-3a)}$$

where:

$EDF_{SHOWER,\exp}$	=	effective dose factor for external exposure to water while showering or bathing (L×mrem)/(pCi×yr)
$F_{t,SHOWER}$	=	fraction of time spent showering or bathing (unitless), Table 7.4-1
GF_{SHOWER}	=	geometry factor for showering or bathing (unitless), Table 7.4-1
DCF_{imm}	=	dose conversion factor for immersion in water (m^3×mrem)/(pCi×yr), Table 7.1-1

3.2.3 Direct Exposure from Swimming

The direct contact exposure pathway from swimming assumes the MOP receptor receives dose from swimming in a contaminated stream at the point of highest concentration. The dose from swimming exposure shall be calculated according to Equation 3.2-4:

$$D_{SL,SWIM\ \exp} = C_{SL} \times EDF_{SWIM\ \exp} \quad \text{(Eq. 3.2-4)}$$

where:

$D_{SL,SWIM\ \exp}$	=	dose (mrem/yr) due to direct exposure from swimming in stream water at the contaminated SL
C_{SL}	=	radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{SWIM\ \exp}$	=	effective dose factor for external exposure to water while swimming (L×mrem)/(pCi×yr), as defined in Equation 3.2-4a, below

The EDF for external exposure to water while swimming shall be calculated as:

$$EDF_{SWIM\ \exp} = F_{t,SWIM} \times GF_{SWIM} \times DCF_{imm} \quad \text{(Eq. 3.2-4a)}$$

where:

$EDF_{SWIM\ \exp}$	=	effective dose factor for external exposure to water while swimming (L×mrem)/(pCi×yr)
$F_{t,SWIM}$	=	fraction of time per year spent swimming (unitless), Table 7.4-1
GF_{SWIM}	=	geometry factor for swimming (unitless), Table 7.4-1
DCF_{imm}	=	dose conversion factor for immersion in water (m^3×mrem)/(pCi×yr), Table 7.1-1

3.2.4 Direct Exposure from Boating

The direct contact exposure pathway from boating assumes the MOP receptor receives dose from activities at a contaminated stream. The dose from boating exposure shall be calculated according to Equation 3.2-5:

$$D_{SL,BOAT\ \exp} = C_{SL} \times EDF_{BOAT\ \exp} \quad \text{(Eq. 3.2-5)}$$

where:

$D_{SL,BOAT\ \exp}$	=	dose to (mrem/yr) due to direct exposure from boating in stream water at the contaminated SL

C_{SL} = radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model

$EDF_{BOAT\,\exp}$ = effective dose factor for external exposure to water while boating (L×mrem)/(pCi×yr), as defined in Equation 3.2-5a, below

The EDF for external exposure to water while boating shall be calculated as:

$$EDF_{BOAT\,\exp} = F_{t,BOAT} \times GF_{BOAT} \times DCF_{imm} \qquad \text{(Eq. 3.2-5a)}$$

where:

$EDF_{BOAT\,\exp}$ = effective dose factor for external exposure to water while boating (L×mrem)/(pCi×yr)

$F_{t,BOAT}$ = fraction of time per year spent boating (unitless), Table 7.4-1

GF_{BOAT} = geometry factor for boating (unitless), Table 7.4-1

DCF_{imm} = dose conversion factor for immersion in water (m^3×mrem)/(pCi×yr), Table 7.1-1

3.3 MOP at the 100-Meter Well, Inhalation Dose Pathways

The following text defines the parameter $D_{MOP,100,inh}$ from Equation 3-1. The inhalation dose to the MOP at the 100-meter well is determined according to Equation 3.3-1:

$$D_{MOP,100,inh} = D_{MOP,100,IRRinh} + D_{MOP,100,DUSTinh} + D_{MOP,100,SHOWERinh} + D_{SL,SWIMinh} \qquad \text{(Eq. 3.3-1)}$$

where:

$D_{MOP,100,inh}$ = dose to the MOP at the 100-meter well (mrem/yr) due to inhalation

$D_{MOP,100,IRRinh}$ = dose to the MOP at the 100-meter well (mrem/yr) due to inhalation while irrigating gardens or crops with water from the 100-meter well

$D_{MOP,100,DUSTinh}$ = dose to the MOP at the 100-meter well (mrem/yr) due to inhalation of dust and soil that has been contaminated due to irrigation with water from the 100-meter well

$D_{MOP,100,SHOWERinh}$ = dose to the MOP at the 100-meter well (mrem/yr) due to inhalation while showering or bathing in water from the 100-meter well

$D_{SL,SWIMinh}$ = dose (mrem/yr) due to inhalation while swimming in stream water at the contaminated SL

3.3.1 Inhalation of Water during Irrigation (MOP at the 100-Meter Well)

The exposure pathway from inhalation during irrigation assumes soil is irrigated with groundwater from the 100-meter well and the MOP receptor is exposed by breathing while the garden is irrigated but only during time spent caring for a garden. The dose is calculated using the following formula:

$$D_{MOP,100,IRRinh} = C_{GW,100} \times EDF_{IRRinh} \qquad \text{(Eq. 3.3-2)}$$

where:

$D_{MOP,100,IRRinh}$ = dose to the MOP at the 100-meter well (mrem/yr) due to inhalation while irrigating gardens or crops with water from the 100-meter well

$C_{GW,100}$ = radionuclide concentration in groundwater from the 100-meter well (pCi/L), as determined from an appropriate contaminant transport model

EDF_{IRRinh} = effective dose factor for inhalation of water during irrigation (L×mrem)/(pCi×yr), as defined in Equation 3.3-2a, below

The EDF for inhalation of water during irrigation shall be calculated as:

$$EDF_{IRRinh} = \frac{U_{air} \times F_{t,g} \times MC_{air} \times ARF \times DCF_{inh}}{\rho_{H2O}} \qquad \text{(Eq. 3.3-2a)}$$

where:

EDF_{IRRinh} = effective dose factor for inhalation of water during irrigation (L×mrem)/(pCi×yr)

U_{air} = air intake (m^3/yr), Table 7.2-1

$F_{t,g}$ = fraction of the time the MOP spends in the garden (unitless), Table 7.4-1

MC_{air} = water contained in air at ambient conditions (kg/m^3), Table 7.4-1

ARF = airborne release fraction (unitless), Table 7.4-1

DCF_{inh} = dose conversion factor for inhalation (mrem/pCi), Table 7.1-1

ρ_{H2O} = water density (kg/L), Table 7.5-3

3.3.2 Inhalation of Dust from Irrigated Soil (MOP at the 100-Meter Well)

The dose pathway associated with inhalation of dust and soil that has been irrigated assumes that dust and soil has been irrigated with groundwater from a 100-meter well and that the MOP receptor is exposed by breathing dust during time spent caring for a garden. This

formula was derived following the approach of previous pathway calculations. The dose is calculated using the following formula:

$$D_{MOP,100,DUSTinh} = C_{GW,100} \times EDF_{DUSTinh} \quad \text{(Eq. 3.3-3)}$$

where:

$D_{MOP,100,DUSTinh}$	=	dose to the MOP at the 100-meter well (mrem/yr) due to inhalation of dust and soil that has been contaminated due to irrigation with water from the 100-meter well
$C_{GW,100}$	=	radionuclide concentration in groundwater from the 100-meter well (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{DUSTinh}$	=	effective dose factor for inhalation of dust and soil (L×mrem)/(pCi×yr), as defined in Equation 3.3-3a, below

The EDF for inhalation of dust and soil shall be calculated as:

$$EDF_{DUSTinh} = U_{air} \times L_{soil} \times SOIL \times I_{RF} \times F_{t,g} \times DCF_{inh} \quad \text{(Eq. 3.3-3a)}$$

where:

$EDF_{DUSTinh}$	=	effective dose factor for inhalation of dust and soil (L×mrem)/(pCi×yr)
U_{air}	=	air intake (m^3/yr), Table 7.2-1
L_{soil}	=	soil loading in air while working in a garden (kg/m^3), Table 7.4-1
$SOIL$	=	radionuclide deposition and buildup rate in the soil ((m^2×yr)/kg) as defined by Equation 3.1-3b
I_{RF}	=	functional irrigation rate (m/yr) as defined by Equation 3.1-3d, above
$F_{t,g}$	=	fraction of the time the MOP spends in the garden (unitless), Table 7.4-1
DCF_{inh}	=	dose conversion factor for inhalation (mrem/pCi), Table 7.1-1

3.3.3 Inhalation during Showering (MOP at the 100-Meter Well)

The showering inhalation dose pathway assumes the MOP receptor is exposed by breathing humid air within the shower. The source of water for the shower is the 100-meter well. The dose is calculated using the following formula:

$$D_{MOP,100,SHOWERinh} = C_{GW,100} \times EDF_{SHOWERinh} \quad \text{(Eq. 3.3-4)}$$

where:

$D_{MOP,100,SHOWERinh}$	=	dose to the MOP at the 100-meter well (mrem/yr) due to inhalation while showering or bathing in water from the 100-meter well
$C_{GW,100}$	=	radionuclide concentration in groundwater from the 100-meter well (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{SHOWERinh}$	=	effective dose factor for inhalation of water while showering or bathing (L×mrem)/(pCi×yr), as defined in Equation 3.3-4a, below

The EDF for inhalation of water while showering or bathing shall be calculated as:

$$EDF_{SHOWERinh} = \frac{U_{air} \times F_{t,SHOWER} \times MC_{SHOWER} \times ARF \times DCF_{inh}}{\rho_{H2O}} \quad \text{(Eq. 3.3-4a)}$$

where:

$EDF_{SHOWERinh}$	=	effective dose factor for inhalation of water while showering or bathing (L×mrem)/(pCi×yr)
U_{air}	=	air intake (m^3/yr), Table 7.2-1
$F_{t,SHOWER}$	=	fraction of time per year spent showering or bathing (unitless), Table 7.4-1
MC_{SHOWER}	=	water contained in air under shower conditions (kg/m^3), Table 7.4-1
ARF	=	airborne release fraction (unitless), Table 7.4-1
DCF_{inh}	=	dose conversion factor for inhalation (mrem/pCi), Table 7.1-1
ρ_{H2O}	=	water density (kg/L), Table 7.5-3

3.3.4 Inhalation during Swimming

The swimming inhalation pathway assumes that water from a stream has been contaminated by groundwater and that the receptor inhales saturated air. For simplicity and conservatism, the moisture contained in the inhaled air is assumed to be from groundwater. The dose is calculated using the following formula:

$$D_{SL,SWIMinh} = C_{SL} \times EDF_{SWIMinh} \quad \text{(Eq. 3.3-5)}$$

where:

$D_{SL,SWIMinh}$	=	dose (mrem/yr) due to inhalation while swimming in stream water at the contaminated SL

C_{SL}	=	radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{SWIMinh}$	=	effective dose factor for inhalation of water while swimming (L×mrem)/(pCi×yr), as defined in Equation 3.3-5a, below

The EDF for inhalation of water while swimming shall be calculated as:

$$EDF_{SWIMinh} = \frac{U_{air} \times F_{t,SWIM} \times MC_{air} \times ARF \times DCF_{inh}}{\rho_{H2O}} \quad \text{(Eq. 3.3-5a)}$$

where:

$EDF_{SWIMinh}$	=	effective dose factor for inhalation of water while swimming (L×mrem)/(pCi×yr)
U_{air}	=	air intake (m^3/yr), Table 7.2-1
$F_{t,SWIM}$	=	fraction of time per year spent swimming (unitless), Table 7.4-1
MC_{air}	=	water contained in air at ambient conditions (kg/m^3), Table 7.4-1
ARF	=	airborne release fraction (unitless), Table 7.4-1
DCF_{inh}	=	dose conversion factor for inhalation (mrem/pCi), Table 7.1-1
ρ_{H2O}	=	water density (kg/L), Table 7.5-3

4.0 MOP AT THE STREAM DOSE PATHWAYS

The following MOP exposure pathways were used in calculating the dose to the MOP receptor with stream water near the contaminated SL as a primary water source. As with the 100-meter well calculations, all transfer times are assumed to be negligible due to the long-term analysis of the PAs.

The dose to the MOP at the SL is determined according to Equation 4-1:

$$D_{MOP,SL} = D_{MOP,SL,ing} + D_{MOP,SL,\exp} + D_{MOP,SL,inh} \quad \text{(Eq. 4-1)}$$

where:

$D_{MOP,SL}$	=	total dose to the MOP at the SL (mrem/yr)
$D_{MOP,SL,ing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion (see Equation 4.1-1)
$D_{MOP,SL,\exp}$	=	dose to the MOP at the SL (mrem/yr) due to exposure (see Equation 4.2-1)
$D_{MOP,SL,inh}$	=	dose to the MOP at the SL (mrem/yr) due to inhalation (see Equation 4.3-1)

4.1 MOP at the SL, Ingestion Dose Pathways

The following text defines the parameter $D_{MOP,SL,ing}$ from Equation 4-1. The ingestion dose to the MOP at the SL is determined according to Equation 4.1-1:

$$\begin{aligned} D_{MOP,SL,ing} = {} & D_{MOP,SL,H2Oing} + D_{MOP,SL,SOILing} + D_{MOP,SL,PLANTing} \\ & + D_{MOP,SL,MEATing} + D_{MOP,SL,MILKing} + D_{MOP,SL,POULTRYing} \\ & + D_{MOP,SL,EGGing} + D_{SL,FISHing} \end{aligned} \quad \text{(Eq. 4.1-1)}$$

where:

$D_{MOP,SL,ing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion
$D_{MOP,SL,H2Oing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion of water from stream water at the contaminated SL
$D_{MOP,SL,SOILing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion of soil that has been irrigated with water from stream water at the contaminated SL
$D_{MOP,SL,PLANTing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion of produce irrigated from stream water at the contaminated SL water
$D_{MOP,SL,MEATing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion of meat (i.e., terrestrial livestock meat such as beef, pork, veal, etc.) that eats fodder watered by and

drinks water from stream water at the contaminated SL

$D_{MOP,SL,MILKing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion of milk that comes from livestock that eats fodder watered by and drinks water from stream water at the contaminated SL
$D_{MOP,SL,POULTRYing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion of poultry (including chicken, turkey, etc.) that eats fodder watered by and drinks water from stream water at the contaminated SL
$D_{MOP,SL,EGGing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion of eggs that come from poultry that eats fodder watered by and drinks water from stream water at the contaminated SL
$D_{SL,FISHing}$	=	dose (mrem/yr) due to ingestion of fish that came from stream water near the contaminated SL, as defined in Equation 3.1-9 (see Section 3.1.8)

Note that the equations described below conservatively assume instant transport of foodstuffs. For example, instead of a period of a few days from the time that meat is slaughtered until it is consumed, the meat is consumed instantly. Given the long time durations expected for PA modeling, this conservative assumption is expected to have a negligible impact on results.

4.1.1 Ingestion of Water (MOP at the SL)

The exposure pathway for water ingestion assumes the MOP receptor uses water from the stream at the SL as a drinking source. The incidental ingestion of water from showering and during recreational activities is assumed negligible when compared to ingestion of drinking water. The dose from consumption of drinking water shall be calculated according to Equation 4.1-2:

$$D_{MOP,SL,H2Oing} = C_{SL} \times EDF_{H2Oing} \qquad \text{(Eq. 4.1-2)}$$

where:

$D_{MOP,SL,H2Oing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion of water from stream water at the contaminated SL
C_{SL}	=	radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model
EDF_{H2Oing}	=	effective dose factor for ingestion of contaminated groundwater (L×mrem)/(pCi×yr), defined in Equation 3.1-2a (see Section 3.1.1)

4.1.2 Ingestion of Soil (MOP at the SL)

Exposure pathway from ingestion of soil assumes the soil is irrigated with groundwater from the SL and the MOP receptor in turn consumes the contaminated soil. This formula was derived following the approach of the previous pathway calculations. A soil buildup factor was applied to account for the buildup of radionuclide concentration in the soil from

successive years of irrigation. The radionuclide concentration in the soil and the dose is calculated using the following formula:

$$D_{MOP,SL,SOILing} = C_{SL} \times EDF_{SOILing} \quad \text{(Eq. 4.1-3)}$$

where:

$D_{MOP,SL,SOILing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion of soil that has been irrigated with water from stream water at the contaminated SL
C_{SL}	=	radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{SOILing}$	=	effective dose factor for ingestion of soil contaminated by groundwater (L×mrem)/(pCi×yr), defined in Equation 3.1-3a (see Section 3.1.2)

4.1.3 Ingestion of Produce (MOP at the SL)

The dose to the MOP receptor from ingestion of contaminated produce (including leafy vegetables, other vegetables, and fruit) is calculated assuming two contamination exposure pathways: (1) direct deposition of contaminated irrigation water on plants and (2) root uptake of contaminated irrigation water in soil. The irrigation water is from the SL. The dose is calculated using Equation 4.1-4:

$$D_{MOP,SL,PLANTing} = C_{SL} \times EDF_{PLANTing} \times F_{local,PLANT} \quad \text{(Eq. 4.1-4)}$$

where:

$D_{MOP,SL,PLANTing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion of produce that has been irrigated with stream water from the contaminated SL
C_{SL}	=	radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{PLANTing}$	=	effective dose factor for ingestion of produce contaminated by groundwater (L×mrem)/(pCi×yr), defined in Equation 3.1-4a (see Section 3.1.3)
$F_{local,PLANT}$	=	fraction of total produce grown locally (unitless), Table 7.6-1

4.1.4 Ingestion of Meat (MOP at the SL)

The meat ingestion pathway assumes that terrestrial livestock drinks contaminated stock water and consumes fodder irrigated with contaminated water. The stock water and irrigation water is from the SL. The fodder is contaminated from direct deposition of contaminated irrigation water on plants and from deposition of contaminated irrigation water in soil followed by root uptake by plants. The buildup of radionuclide concentration in the soil from successive years of irrigation is accounted for. The radionuclide concentration in fodder from deposition and root uptake is calculated as well.

For the purpose of this calculation, meat (or terrestrial livestock) includes all meat that is not considered poultry or fish. This includes beef, pork, veal, and other game.

Following the terrestrial livestock consumption of the contaminated water and fodder, the MOP receptor consumes the contaminated meat. The dose from ingesting contaminated meat is calculated using the following formula:

$$D_{MOP,SL,MEATing} = C_{SL} \times EDF_{MEATing} \times F_{local,MEAT} \quad \text{(Eq. 4.1-5)}$$

where:

$D_{MOP,SL,MEATing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion of meat (i.e., terrestrial livestock meat such as beef, pork, veal, etc.) that eats fodder watered by and drinks water from stream water at the contaminated SL water
C_{SL}	=	radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{MEATing}$	=	effective dose factor for ingestion of terrestrial livestock meat contaminated by groundwater (L×mrem)/(pCi×yr), as defined in Equation 3.1-5a (see Section 3.1.4)
$F_{local,MEAT}$	=	fraction of terrestrial livestock raised locally (unitless), Table 7.6-1

4.1.5 Ingestion of Milk (MOP at the SL)

Following the livestock consumption of the contaminated water and fodder, the MOP receptor consumes the contaminated milk from the livestock cattle. The dose from ingestion of contaminated milk is calculated using the following formula:

$$D_{MOP,SL,MILKing} = C_{SL} \times EDF_{MILKing} \times F_{local,MILK} \quad \text{(Eq. 4.1-6)}$$

where:

$D_{MOP,SL,MILKing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion of milk that comes from milk-producing livestock that eats fodder watered by and drinks water from stream water at the contaminated SL
C_{SL}	=	radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{MILKing}$	=	effective dose factor for ingestion of milk contaminated by groundwater (L×mrem)/(pCi×yr), as defined in Equation 3.1-6a (see Section 3.1.5)
$F_{local,MILK}$	=	fraction of milk-producing livestock raised locally (unitless), Table 7.6-1

4.1.6 Ingestion of Poultry (MOP at the SL)

The poultry and egg ingestion pathways assume poultry drink contaminated stock water and consume fodder irrigated with contaminated water. The stock water and irrigation water is from the SL. The fodder is contaminated from direct deposition of contaminated irrigation water on plants and from deposition of contaminated irrigation water in soil followed by root uptake by plants. For conservatism, it is also assumed that poultry directly ingest contaminated soil in addition to the stock water and fodder. The dose from ingestion of contaminated poultry is calculated using the following formula:

$$D_{MOP,SL,POULTRYing} = C_{SL} \times EDF_{POULTRYing} \times F_{local,POULTRY} \quad \text{(Eq. 4.1-7)}$$

where:

$D_{MOP,SL,POULTRYing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion of poultry (including chicken, turkey, etc.) that eats fodder watered by and drinks water from stream water at the contaminated SL
C_{SL}	=	radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{POULTRYing}$	=	effective dose factor for ingestion of poultry contaminated by groundwater (L×mrem)/(pCi×yr), as defined in Equation 3.1-7a (see Section 3.1.6)
$F_{local,POULTRY}$	=	fraction of poultry raised locally (unitless), Table 7.6-1

4.1.7 Ingestion of Egg (MOP at the SL)

Following the poultry consumption of the contaminated water and fodder, the MOP consumes the contaminated eggs. The dose from ingestion of contaminated eggs is calculated using the following formula:

$$D_{MOP,SL,EGGing} = C_{SL} \times EDF_{EGGing} \times F_{local,EGG} \quad \text{(Eq. 4.1-8)}$$

where:

$D_{MOP,SL,EGGing}$	=	dose to the MOP at the SL (mrem/yr) due to ingestion of eggs that come from poultry that eats fodder watered by and drinks water from stream water at the contaminated SL
C_{SL}	=	radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model
EDF_{EGGing}	=	effective dose factor for ingestion of eggs contaminated by groundwater (L×mrem)/(pCi×yr), as defined in Equation 3.1-8a (see Section 3.1.7)
$F_{local,EGG}$	=	fraction of eggs produced locally (unitless), Table 7.6-1

4.1.8 Ingestion of Fish

The fish ingestion route assumes fish are caught from a stream contaminated stream at the point of highest concentration, and the MOP receptor in turn consumes the contaminated fish. The dose from consumption of fish shall be calculated according to Equation 3.1-9 (see Section 3.1.8).

4.2 MOP at the SL, Direct Exposure Dose Pathways

The following text defines the parameter $D_{MOP,SL,\exp}$ from Equation 4-1. The direct exposure dose to the MOP at the SL is determined according to Equation 4.2-1:

$$D_{MOP,SL,\exp} = D_{MOP,SL,SOIL\,\exp} + D_{MOP,SL,SHOWER,\exp} + D_{SL,SWIM\,\exp} + D_{SL,BOAT\,\exp} \quad \text{(Eq. 4.2-1)}$$

where:

$D_{MOP,SL,\exp}$	=	dose to the MOP at the SL (mrem/yr) due to exposure
$D_{MOP,SL,SOIL\,\exp}$	=	dose to the MOP at the SL (mrem/yr) due to direct exposure to soil irrigated from stream water at the SL
$D_{MOP,SL,SHOWER,\exp}$	=	dose to the MOP at the SL (mrem/yr) due to direct exposure while showering or bathing in water from stream water at the SL
$D_{SL,SWIM\,\exp}$	=	dose (mrem/yr) due to direct exposure from swimming in stream water at the contaminated SL, as defined in Equation 3.2-4 (see Section 3.2.3)
$D_{SL,BOAT\,\exp}$	=	dose (mrem/yr) due to direct exposure from boating in stream water at the contaminated SL, as defined in Equation 3.2-5 (see Section 3.2.4)

Note that direct exposure from fishing at the shoreline of a contaminated stream is considered negligible relative to the other exposure pathways and is not included in this methodology.

4.2.1 Direct Exposure from Irrigated Soil (MOP at the SL)

The exposure pathway from direct contact to contaminated soil assumes the soil is irrigated with groundwater from the SL and the MOP receptor in turn is exposed during time spent caring for a garden. The radionuclide concentration in the soil and the exposure dose is calculated using the following formula:

$$D_{MOP,SL,SOIL\,\exp} = C_{SL} \times EDF_{SOIL\,\exp} \quad \text{(Eq. 4.2-2)}$$

where:

$D_{MOP,SL,SOIL\,\exp}$	=	dose to the MOP at the SL (mrem/yr) due to direct exposure to soil irrigated from water at the SL
C_{SL}	=	radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model

$EDF_{SOIL\ \exp}$	=	effective dose factor for external exposure to soil (L×mrem)/(pCi×yr), as defined in Equation 3.2-2a (see Section 3.2.1)

4.2.2 Direct Exposure from Showering (MOP at the SL)

The direct contact exposure pathway from showering and bathing assumes the MOP receptor receives dose from washing in water from the SL. The dose is calculated using the following formula:

$$D_{MOP,SL,SHOWER,\exp} = C_{SL} \times EDF_{SHOWER,\exp} \quad \text{(Eq. 4.2-3)}$$

where:

$D_{MOP,SL,SHOWER,\exp}$	=	dose to the MOP at the SL (mrem/yr) due to direct exposure while showering or bathing in water from the contaminated SL
C_{SL}	=	radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{SHOWER,\exp}$	=	effective dose factor for external exposure to water while showering or bathing (L×mrem)/(pCi×yr), as defined in Equation 3.2-3a (see Section 3.2.2)

4.2.3 Direct Exposure from Swimming

The direct contact exposure pathway from swimming assumes the MOP receptor receives dose from swimming in a contaminated stream at the point of highest concentration. The dose from swimming exposure shall be calculated according to Equation 3.2-4 (see Section 3.2.3).

4.2.4 Direct Exposure from Boating

The direct contact exposure pathway from boating assumes the MOP receptor receives dose from swimming in a contaminated stream at the point of highest concentration. The dose from boating exposure shall be calculated according to Equation 3.2-5 (see Section 3.2.4).

4.3 MOP at the SL, Inhalation Dose Pathways

The following text defines the parameter $D_{MOP,SL,inh}$ from Equation 4-1. The inhalation dose to the MOP at the SL is determined according to Equation 4.3-1:

$$D_{MOP,SL,inh} = D_{MOP,SL,IRRinh} + D_{MOP,SL,DUSTinh} + D_{MOP,SL,SHOWERinh} + D_{SL,SWIMinh} \quad \text{(Eq. 4.3-1)}$$

where:

$D_{MOP,SL,inh}$	=	dose to the MOP at the SL (mrem/yr) due to inhalation

$D_{MOP,SL,IRRinh}$ = dose to the MOP at the SL (mrem/yr) due to inhalation while irrigating gardens or crops with water from the contaminated SL

$D_{MOP,SL,DUSTinh}$ = dose to the MOP at the SL (mrem/yr) due to inhalation of dust and soil that has been contaminated due to irrigation with water from the contaminated SL

$D_{MOP,SL,SHOWERinh}$ = dose to the MOP at SL (mrem/yr) due to inhalation while showering or bathing in water from the contaminated SL

$D_{SL,SWIMinh}$ = dose (mrem/yr) due to inhalation while swimming in stream water at the contaminated SL , as defined in Equation 3.3-5 (see Section 3.3.4)

4.3.1 Inhalation of Water during Irrigation (MOP at the SL)

The exposure pathway from inhalation during irrigation assumes soil is irrigated with groundwater from the contaminated SL and the MOP receptor is exposed by breathing while the garden is irrigated but only during time spent caring for a garden. The dose is calculated using the following formula:

$$D_{MOP,SL,IRRinh} = C_{SL} \times EDF_{IRRinh} \qquad \text{(Eq. 4.3-2)}$$

where:

$D_{MOP,SL,IRRinh}$ = dose to the MOP at the SL (mrem/yr) due to inhalation while irrigating gardens or crops with water from the contaminated SL

C_{SL} = radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model

EDF_{IRRinh} = effective dose factor for inhalation of water during irrigation (L×mrem)/(pCi×yr), as defined in Equation 3.3-2a (see Section 3.3.1)

4.3.2 Inhalation of Dust from Irrigated Soil (MOP at the SL)

The dose pathway associated with inhalation of dust and soil that has been irrigated assumes that dust and soil has been irrigated with water from the contaminated SL and that the MOP receptor is exposed by breathing dust during time spent caring for a garden. This formula was derived following the approach of previous pathway calculations. The dose is calculated using the following formula:

$$D_{MOP,SL,DUSTinh} = C_{SL} \times EDF_{DUSTinh} \qquad \text{(Eq. 4.3-3)}$$

where:

$D_{MOP,SL,DUSTinh}$ = dose to the MOP at the SL (mrem/yr) due to inhalation of dust and soil that has been contaminated due to irrigation with water from the contaminated SL

C_{SL} = radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model

$EDF_{DUSTinh}$ = effective dose factor for inhalation of dust and soil (L×mrem)/(pCi×yr), as defined in Equation 3.3-3a (see Section 3.3.2)

4.3.3 Inhalation during Showering (MOP at the SL)

The showering inhalation dose pathway assumes the MOP receptor is exposed by breathing humid air within the shower. The source of water for the shower is the stream at the contaminated SL. The dose is calculated using the following formula:

$$D_{MOP,SL,SHOWERinh} = C_{SL} \times EDF_{SHOWERinh} \quad \text{(Eq. 4.3-4)}$$

where:

$D_{MOP,SL,SHOWERinh}$ = dose to the MOP at SL (mrem/yr) due to inhalation while showering or bathing in water from the contaminated SL

C_{SL} = radionuclide concentration in stream water at the contaminated SL (pCi/L), as determined from an appropriate contaminant transport model

$EDF_{SHOWERinh}$ = effective dose factor for inhalation of water while showering or bathing (L×mrem)/(pCi×yr), as defined in Equation 3.3-4a (see Section 3.3.3)

4.3.4 Inhalation during Swimming

The swimming inhalation pathway assumes that water from a stream has been contaminated by groundwater and the receptor inhales saturated air. For simplicity and conservatism, the amount of moisture contained in the inhaled air is assumed to be groundwater. The dose is calculated using Equation 3.3-5 (see Section 3.3.4).

5.0 ACUTE IHI DOSE PATHWAYS

The acute IHI scenario assumes that (1) a drill is installed that penetrates the closed liquid waste facility and (2) the IHI receptor, in turn, is exposed to ingestion and inhalation of dust and material from drill cuttings, and direct exposure through handling the contaminated drill cuttings.

The following IHI exposure pathways were used in calculating the acute dose to the IHI receptor from contaminated drill cuttings. The dose to the acute IHI is determined according to Equation 5-1:

$$D_{IHIA} = D_{IHIA,ing} + D_{IHIA,\exp} + D_{IHIA,inh} \quad \text{(Eq. 5-1)}$$

where:

D_{IHIA} = total dose to the acute IHI (mrem)

$D_{IHIA,ing}$ = dose to the acute IHI (mrem) due to ingestion (see Equation 5.1-1)

$D_{IHIA,\exp}$ = dose to the acute IHI (mrem) due to exposure (see Equation 5.2-1)

$D_{IHIA,inh}$ = dose to the acute IHI (mrem) due to inhalation (see Equation 5.3-1)

5.1 Acute IHI, Ingestion Dose Pathways

The following text defines the parameter $D_{IHIA,ing}$ from Equation 5-1. The acute IHI ingestion dose is due to the resuspension of material during drilling activities. The acute IHI ingestion dose is determined according to Equation 5.1-1:

$$D_{IHIA,ing} = C_{IHIA} \times EDF_{IHIA,ing} \quad \text{(Eq. 5.1-1)}$$

where:

$D_{IHIA,ing}$ = dose to the acute IHI (mrem) due to ingestion

C_{IHIA} = radionuclide concentration in contaminated drill cuttings (pCi/m^3), defined in Equation 5.1-1b, below

$EDF_{IHIA,ing}$ = effective dose factor for ingestion of contaminated drill cutting (L×mrem)/(pCi), defined in Equation 5.1-1a, below

The EDF for ingestion of dust from drill cuttings shall be calculated as:

$$EDF_{IHIA,ing} = \frac{\left(F_{t,d} \times 1yr\right) \times U_{soil} \times DCF_{ing}}{\rho_s} \quad \text{(Eq. 5.1-1a)}$$

where:

$EDF_{IHIA,ing}$	=	effective dose factor for ingestion of contaminated drill cutting (L×mrem)/(pCi)
$F_{t,d}$	=	fraction of time exposed to drill cuttings (unitless), Table 7.4-1
U_{soil}	=	human consumption rate of soil (kg/yr), Table 7.2-1
DCF_{ing}	=	ingestion dose conversion factor (mrem/pCi), Table 7.1-1
ρ_S	=	dry bulk density of soil (kg/m^3), Table 7.5-1

The drill cutting concentration can be determined as a function of the maximum drill core activity and the geometry of the drilled well:

$$C_{IHIA} = \frac{Act_{\max}}{\pi\left(\frac{well_{diam}}{2}\right)^2 \times well_{dep}} \qquad \text{(Eq. 5.1-1b)}$$

where:

C_{IHIA}	=	radionuclide concentration in contaminated drill cuttings (pCi/m^3)
$Act_{\max}$	=	maximum drilled core activity or mass (pCi), defined prior to dose calculation based on the inventory from the source of the contaminated drill cuttings
$well_{diam}$	=	well diameter (m), Table 7.5-3
$well_{dep}$	=	well depth (m), Table 7.5-3

5.2 Acute IHI, Direct Exposure Dose Pathways

The following text defines the parameter $D_{IHIA,\exp}$ from Equation 5-1. The acute IHI direct exposure dose is due to direct contact with contaminated material during drilling activities. The acute IHI exposure dose is determined according to Equation 5.2-1:

$$D_{IHIA,\exp} = C_{IHIA} \times EDF_{IHIA,\exp} \qquad \text{(Eq. 5.2-1)}$$

where:

$D_{IHIA,\exp}$	=	dose to the acute IHI (mrem) due to exposure

C_{IHIA}	=	radionuclide concentration in contaminated drill cuttings (pCi/m[3]), see Equation 5.1-1b, above
$EDF_{IHIA,\exp}$	=	effective dose factor for direct exposure of contaminated drill cuttings (L×mrem)/(pCi), defined in Equation 5.2-1a, below

The EDF for direct exposure to drill cuttings shall be calculated as:

$$EDF_{IHIA,\exp} = \left(F_{t,d} \times 1yr\right) \times DCF_{\exp} \qquad \text{(Eq. 5.2-1a)}$$

where:

$EDF_{IHIA,\exp}$	=	effective dose factor for direct exposure of contaminated drill cuttings (L×mrem)/(pCi)
$F_{t,d}$	=	fraction of time exposed to drill cuttings (unitless), Table 7.4-1
$DCF_{\exp}$	=	dose conversion factor for external exposure (m^3×mrem)/(pCi×yr), Table 7.1-1

5.3 Acute IHI, Inhalation Dose Pathways

The following text defines the parameter $D_{IHIA,inh}$ from Equation 5-1. The acute IHI inhalation dose is due to the resuspension of material during drilling activities. The acute IHI inhalation dose is determined according to Equation 5.3-1:

$$D_{IHIA,inh} = C_{IHIA} \times EDF_{IHIA,inh} \qquad \text{(Eq. 5.3-1)}$$

where:

$D_{IHIA,inh}$	=	dose to the acute IHI (mrem) due to inhalation
C_{IHIA}	=	radionuclide concentration in contaminated drill cuttings (pCi/m[3]), see Equation 5.1-1a (above)
$EDF_{IHIA,inh}$	=	effective dose factor inhalation of dust from contaminated drill cuttings (L×mrem)/(pCi), defined in Equation 5.3-1a, below

The EDF for inhalation of dust from drill cuttings shall be calculated as:

$$EDF_{IHIA,inh} = \frac{\left(F_{t,d} \times 1yr\right) \times L_{soil} \times U_{air} \times DCF_{inh}}{\rho_s} \qquad \text{(Eq. 5.3-1a)}$$

where:

$EDF_{IHIA,inh}$ = effective dose factor inhalation of dust from contaminated drill cuttings (L×mrem)/(pCi)

$F_{t,d}$ = fraction of time exposed to drill cuttings (unitless), Table 7.4-1

L_{soil} = soil loading in air while working in a garden (kg/m^3), Table 7.4-1

U_{air} = air intake (m^3/yr), Table 7.2-1

DCF_{inh} = dose conversion factor for inhalation (mrem/pCi), Table 7.1-1

ρ_S = dry bulk density of soil (kg/m^3), Table 7.5-1

6.0 CHRONIC IHI DOSE PATHWAYS

Provided below are the individual elements of the Chronic IHI biotic pathways. The chronic intruder exposure pathways detailed below are used in calculating the dose to the chronic intruder receptor with a hypothetical 1-meter well water as a primary water source. The stream is the secondary water source for the pathways involving swimming, boating, and fish ingestion. All transfer times are assumed negligible due to the long-term analysis of the PA.

The chronic dose to the IHI is determined according to Equation 6-1:

$$D_{IHIC} = D_{IHIC,ing} + D_{IHIC,\exp} + D_{IHIC,inh} \quad \text{(Eq. 6-1)}$$

where:

D_{IHIC}	=	total dose to the chronic IHI (mrem/yr)
$D_{IHIC,ing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion (see Equation 6.1-1)
$D_{IHIC,\exp}$	=	dose to the chronic IHI (mrem/yr) due to exposure (see Equation 6.2-1)
$D_{IHIC,inh}$	=	dose to the chronic IHI (mrem/yr) due to inhalation (see Equation 6.3-1)

6.1 Chronic IHI, Ingestion Dose Pathways

The following text defines the parameter $D_{IHIC,ing}$ from Equation 6-1. The ingestion dose to the chronic IHI is determined according to Equation 6.1-1:

$$\begin{aligned} D_{IHIC,ing} = {} & D_{IHIC,H2Oing} + D_{IHIC,SOILing} + D_{IHIC,PLANTing} \\ & + D_{IHIC,MEATing} + D_{IHIC,MILKing} + D_{IHIC,POULTRYing} \\ & + D_{IHIC,EGGing} + D_{SL,FISHing} \end{aligned} \quad \text{(Eq. 6.1-1)}$$

where:

$D_{IHIC,ing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion
$D_{IHIC,H2Oing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of water from the 1-meter well
$D_{IHIC,SOILing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of soil that has been irrigated with water from the 1-meter well
$D_{IHIC,PLANTing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of produce (both fruits and vegetables) irrigated from the 1-meter well water and contaminated by the deposition of drill cuttings

$D_{IHIC,MEATing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of meat (i.e., terrestrial livestock meat such as beef, pork, veal, etc.) that eats fodder watered by and drinks water from the 1-meter well and contaminated by the deposition of drill cuttings

$D_{IHIC,MILKing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of milk that comes from livestock that eats fodder watered by and drinks water from the 1-meter well and contaminated by the deposition of drill cuttings

$D_{IHIC,POULTRYing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of poultry (including chicken, turkey, etc.) that eats fodder watered by and drinks water from the 1-meter well and contaminated by the deposition of drill cuttings

$D_{IHIC,EGGing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of eggs that come from poultry that eats fodder watered by and drinks water from the 1-meter well and contaminated by the deposition of drill cuttings

$D_{SL,FISHing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of fish that came from stream water near the contaminated SL, as defined in Equation 3.1-9 (see Section 3.1.8)

Note that the equations described below conservatively assume instant transport of foodstuffs. For example, instead of a period of a few days from the time that meat is slaughtered until it is consumed, the meat is consumed instantly. Given the long time durations expected for PA modeling, this conservative assumption is expected to have a negligible impact on results.

6.1.1 Ingestion of Water (Chronic IHI)

The drinking water exposure route assumes a well 1-meter from the source is used by the IHI receptor as a drinking water source. The incidental ingestion of water from showering and during recreational activities is assumed negligible when compared to ingestion of drinking water. The dose from consumption of drinking water is calculated using the following formula:

$$D_{IHIC,H2Oing} = C_{IHIC} \times EDF_{H2Oing} \qquad \text{(Eq. 6.1-2)}$$

where:

$D_{IHIC,H2Oing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of water from the 1-meter well

C_{IHIC} = radionuclide concentration in groundwater from the 1-meter well (pCi/L), as determined from an appropriate contaminant transport model

EDF_{H2Oing} = effective dose factor for ingestion of contaminated groundwater (L×mrem)/(pCi×yr), defined in Equation 3.1-2a (see Section 3.1.1)

6.1.2 Ingestion of Soil (Chronic IHI)

The soil ingestion exposure pathway assumes soil is contaminated from two contamination sources: (1) the soil is irrigated with groundwater from the 1-meter well and (2) deposition of contaminated drill cuttings in the garden soil, as follows:

$$D_{IHIC,SOILing} = D_{IHIC,H2OSOILing} + D_{IHIC,DrillSOILing} \quad \text{(Eq. 6.1-3)}$$

where:

$D_{IHIC,SOILing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of soil

$D_{IHIC,H2OSOILing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of soil that has been irrigated with water from the 1-meter well

$D_{IHIC,DrillSOILing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of soil that has been contaminated by drill cuttings

The dose from ingestion of soil irrigated by 1-meter well water, $D_{IHIC,H2OSOILing}$, as used in Equation 6.1-3, is determined according to the following:

$$D_{IHIC,H2OSOILing} = C_{IHIC} \times EDF_{SOILing} \quad \text{(Eq. 6.1-3a)}$$

where:

$D_{IHIC,H2OSOILing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of soil that has been irrigated with water from the 1-meter well

C_{IHIC} = radionuclide concentration in groundwater from the 1-meter well (pCi/L), as determined from an appropriate contaminant transport model

$EDF_{SOILing}$ = effective dose factor for ingestion of soil contaminated by groundwater (L×mrem)/(pCi×yr), defined in Equation 3.1-3a (see Section 3.1.2)

Similarly, dose from ingestion of soil contaminated by drill cuttings, $D_{IHIC,DrillSOILing}$, is determined according to Equation 6.1-3b:

$$D_{IHIC,DrillSOILing} = C_{IHI,g} \times EDF_{IHI,SOILing} \quad \text{(Eq. 6.1-3b)}$$

where:

$D_{IHIC,DrillSOILing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of soil that has been contaminated by drill cuttings

$C_{IHI,g}$ = radionuclide concentration in the garden from contaminated drill cuttings (pCi/m^3), as defined by Equation 6.1-3c (below)

$EDF_{IHI,SOILing}$ = effective dose factor for ingestion of soil contaminated by drill cuttings (L×mrem)/(pCi×yr), defined in Equation 6.1-3d, below

The IHI drill cuttings are assumed to be mixed into the volume of the garden:

$$C_{IHI,g} = \frac{Act_{\max}}{A_{garden} \times d_{till}} \qquad \text{(Eq. 6.1-3c)}$$

where:

$C_{IHI,g}$	=	radionuclide concentration in the garden from contaminated drill cuttings (pCi/m^3)
$Act_{\max}$	=	maximum drilled core activity or mass (pCi), defined prior to dose calculation based on the inventory from the source of the contaminated drill cuttings
A_{garden}	=	garden area (m^2), Table 7.5-2
d_{till}	=	depth of tilling for agriculture or gardening (m), Table 7.5-2

The EDF for ingestion of soil and dust contaminated by drill cuttings shall be calculated as:

$$EDF_{IHI,SOILing} = \frac{F_{t,g} \times U_{soil} \times DCF_{ing}}{\rho_s} \qquad \text{(Eq. 6.1-3d)}$$

where:

$EDF_{IHI,SOILing}$	=	effective dose factor for ingestion of soil contaminated by drill cuttings (L×mrem)/(pCi×yr)
$F_{t,g}$	=	fraction of the time the IHI spends in the garden (unitless), Table 7.4-1
U_{soil}	=	human consumption rate of soil (kg/yr), Table 7.2-1
DCF_{ing}	=	dose conversion factor for ingestion (mrem/pCi), Table 7.1-1
ρ_S	=	dry bulk density of soil (kg/m^3), Table 7.5-1

6.1.3 Ingestion of Produce (Chronic IHI)

The chronic dose to the IHI receptor from ingestion of contaminated produce (including leafy vegetables, other vegetables, and fruit) is calculated assuming two contamination sources: (1)

the soil is irrigated with groundwater from the 1-meter well and (2) deposition of contaminated drill cuttings in the garden soil, as follows:

$$D_{IHIC,PLANTing} = \left(D_{IHIC,H2OPLANTing} + D_{IHIC,DrillPLANTing}\right) \times F_{IHI,local,PLANT} \quad \text{(Eq. 6.1-4)}$$

where:

$D_{IHIC,PLANTing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of produce
$D_{IHIC,H2OPLANTing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of produce that has been irrigated with water from the 1-meter well
$D_{IHIC,DrillPLANTing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of produce that has been contaminated by drill cuttings
$F_{IHI,local,PLANT}$	=	fraction of consumed produce grown locally (unitless), Table 7.6-1

The dose from ingestion of plants contaminated by groundwater $D_{IHIC,H2OPLANTing}$ is calculated using the following formula:

$$D_{IHIC,H2OPLANTing} = C_{IHIC} \times EDF_{PLANTing} \quad \text{(Eq. 6.1-4a)}$$

where:

$D_{IHIC,H2OPLANTing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of produce that has been irrigated with water from the 1-meter well
C_{IHIC}	=	radionuclide concentration in groundwater from the 1-meter well (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{PLANTing}$	=	effective dose factor for ingestion of plants contaminated by groundwater (L×mrem)/(pCi×yr), defined in Equation 3.1-4a (see Section 3.1.3)

The dose from ingestion of plants contaminated by drill cuttings $D_{IHIC,DrillPLANTing}$ is calculated using the following formula:

$$D_{IHIC,DrillPLANTing} = C_{IHI,g} \times EDF_{IHI,PLANTing} \quad \text{(Eq. 6.1-4b)}$$

where:

$D_{IHIC,DrillPLANTing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of soil that has been contaminated by drill cuttings
$C_{IHI,g}$	=	radionuclide concentration in the garden from contaminated drill cuttings (pCi/m^3), as defined by Equation 6.1-3c (above)

$EDF_{IHI,PLANTing}$ = effective dose factor for ingestion of plants contaminated by drill cuttings (L×mrem)/(pCi×yr), defined in Equation 6.1-4c, below

The EDF for the dose from ingestion of plants contaminated by drill cuttings shall be calculated as:

$$EDF_{IHI,PLANTing} = \frac{(R_{StoV} \times U_P \times DCF_{ing})}{\rho_S} \qquad \text{(Eq. 6.1-4c)}$$

where:

$EDF_{IHI,PLANTing}$ = effective dose factor for ingestion of plants contaminated by drill cuttings (L×mrem)/(pCi×yr)

R_{StoV} = soil to vegetation ratio (unitless), Table 7.3-1

U_P = human consumption rate of plants or produce (kg/yr), as defined in Equation 3.1-4e (see Section 3.1.3)

DCF_{ing} = ingestion dose conversion factor (mrem/pCi), Table 7.1-1

ρ_S = dry bulk density of soil (kg/m^3), Table 7.5-1

6.1.4 Ingestion of Meat (Chronic IHI)

The meat ingestion pathway assumes that terrestrial livestock drinks contaminated stock water and consumes fodder irrigated with contaminated water. The stock water and irrigation water is from the 1-meter well. The fodder is contaminated from direct deposition of contaminated irrigation water on plants, from deposition of contaminated irrigation water in soil followed by root uptake by plants, and from drill cuttings. The buildup of radionuclide concentration in the soil from successive years of irrigation is accounted for. The radionuclide concentration in fodder from deposition and root uptake is calculated as well.

For the purpose of this calculation, meat (or terrestrial livestock) includes all meat that is not considered poultry or fish. This includes beef, pork, veal, and other game.

Following the terrestrial livestock consumption of the contaminated water and fodder, the IHI receptor consumes the contaminated meat. The dose from ingesting contaminated meat is calculated using the following formula:

$$D_{IHIC,MEATing} = (D_{IHIC,H2OMEATing} + D_{IHIC,DrillMEATing}) \times F_{IHI,local,MEAT} \qquad \text{(Eq. 6.1-5)}$$

where:

$D_{IHIC,MEATing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of meat (i.e., terrestrial livestock meat such as beef, pork, veal, etc.)
$D_{IHIC,H2OMEATing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of meat (i.e., terrestrial livestock meat such as beef, pork, veal, etc.) that has been irrigated with water from the 1-meter well
$D_{IHIC,DrillMEATing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of meat (i.e., terrestrial livestock meat such as beef, pork, veal, etc.) that has been contaminated by drill cuttings
$F_{IHI,local,MEAT}$	=	fraction of consumed terrestrial livestock raised locally (unitless), Table 7.6-1

The dose from ingestion of meat that has been contaminated by groundwater $D_{IHIC,H2OMEATing}$ is calculated using the following formula:

$$D_{IHIC,H2OMEATing} = C_{IHIC} \times EDF_{MEATing} \quad \text{(Eq. 6.1-5a)}$$

where:

$D_{IHIC,H2OMEATing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of meat (i.e., terrestrial livestock such as beef, pork, veal, etc.) that has been irrigated with water from the 1-meter well
C_{IHIC}	=	radionuclide concentration in groundwater from the 1-meter well (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{MEATing}$	=	effective dose factor for ingestion of terrestrial livestock meat contaminated by groundwater (L×mrem)/(pCi×yr), as defined in Equation 3.1-5a (see Section 3.1.4)

The dose from ingestion of meat contaminated by drill cuttings $D_{IHIC,DrillMEATing}$ is calculated using the following formula:

$$D_{IHIC,DrillMEATing} = C_{IHIC,g} \times EDF_{IHI,MEATing} \quad \text{(Eq. 6.1-5b)}$$

where:

$D_{IHIC,DrillMEATing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of meat (i.e., terrestrial livestock meat such as beef, pork, veal, etc.) that has been contaminated by drill cuttings
$C_{IHI,g}$	=	radionuclide concentration in the garden from contaminated drill cuttings (pCi/m^3), as defined by Equation 6.1-3c (above)
$EDF_{IHI,MEATing}$	=	effective dose factor for ingestion of terrestrial livestock meat contaminated by drill cuttings (L×mrem)/(pCi×yr), as defined in Equation 6.1-5c, below

The EDF for the dose from ingestion of meat contaminated by drill cuttings shall be calculated as:

$$EDF_{IHI,MEATing} = \left(\left(Q_{fod,MEAT} \times \left(R_{StoV} \times SOIL\right) \times F_{fodIHI,MEAT}\right) \times \left(PR + I_{RF} - ER\right)\right) \times TC_{MEAT} \times U_{MEAT} \times DCF_{ing} \quad \text{(Eq. 6.1-5c)}$$

where:

$EDF_{IHI,MEATing}$	=	effective dose factor for ingestion of terrestrial livestock meat contaminated by drill cuttings (L×mrem)/(pCi×yr)
$Q_{fod,MEAT}$	=	consumption rate of fodder by terrestrial livestock (kg/yr), Table 7.2-2
R_{StoV}	=	soil to vegetation ratio (unitless), Table 7.3-1
$SOIL$	=	radionuclide deposition and ((m^2×yr)/kg), as defined in Equation 3.1-3b (see Section 3.1.3)
$F_{fodIHI,MEAT}$	=	fraction of terrestrial livestock intake from field/pasture that is contaminated by drill cuttings (unitless), Table 7.2-3
PR	=	precipitation rate (m/yr), Table 7.5-1
I_{RF}	=	functional irrigation rate (m/yr) as defined by Equation 3.1-3d (see Section 3.1.2)
ER	=	evapotranspiration rate (m/yr), Table 7.5-1
TC_{MEAT}	=	transfer coefficient for meat (i.e., terrestrial livestock meat such as beef, pork, veal, etc.) (yr/kg), Table 7.3-2
U_{MEAT}	=	human consumption rate of meat (i.e., terrestrial livestock meat such as beef, pork, veal, etc.) (kg/yr), Table 7.2-1
DCF_{ing}	=	dose conversion factor for ingestion (mrem/pCi), Table 7.1-1

6.1.5 Ingestion of Milk (Chronic IHI)

Following the livestock consumption of the contaminated water and fodder, the IHI receptor consumes the contaminated milk from the livestock cattle. The dose from ingestion of contaminated milk is calculated using the following formula:

$$D_{IHIC,MILKing} = \left(D_{IHIC,H2OMILKing} + D_{IHIC,DrillMILKing}\right) \times F_{IHI,local,MILK} \quad \text{(Eq. 6.1-6)}$$

where:

$D_{IHIC,MILKing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of milk

$D_{IHIC,H2OMILKing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of milk that has been irrigated with water from the 1-meter well

$D_{IHIC,DrillMILKing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of milk that has been contaminated by drill cuttings

$F_{IHI,local,MILK}$ = fraction of consumed milk produced locally (unitless), Table 7.6-1

The dose from ingestion of milk contaminated by groundwater $D_{IHIC,H2OMILKing}$ is calculated using the following formula:

$$D_{IHIC,H2OMILKing} = C_{IHIC} \times EDF_{MILKing} \quad \text{(Eq. 6.1-6a)}$$

where:

$D_{IHIC,H2OMILKing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of milk that has been irrigated with water from the 1-meter well

C_{IHIC} = radionuclide concentration in groundwater from the 1-meter well (pCi/L), as determined from an appropriate contaminant transport model

$EDF_{MILKing}$ = effective dose factor for ingestion of milk contaminated by groundwater (L×mrem)/(pCi×yr), as defined in Equation 3.1-6a (see Section 3.1.5)

The dose from ingestion of milk contaminated by drill cuttings $D_{IHIC,DrillMILKing}$ is calculated using the following formula:

$$D_{IHIC,DrillMILKing} = C_{IHIC,g} \times EDF_{IHI,MILKing} \quad \text{(Eq. 6.1-6b)}$$

where:

$D_{IHIC,DrillMILKing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of milk that has been contaminated by drill cuttings

$C_{IHI,g}$ = radionuclide concentration in the garden from contaminated drill cuttings (pCi/m^3), as defined by Equation 6.1-3c (above)

$EDF_{IHI,MILKing}$ = effective dose factor for ingestion of milk contaminated by drill cuttings (L×mrem)/(pCi×yr), as defined in Equation 6.1-6c, below

The EDF for the dose from ingestion of milk contaminated by drill cuttings shall be calculated as:

$$EDF_{IHI,MILKing} = \left(\left(Q_{fod,MILK} \times \left(R_{StoV} \times SOIL\right) \times F_{fod,MILK}\right) \times \left(PR + I_{RF} - ER\right)\right) \times TC_{MILK} \times \left(\frac{U_{MILK}}{\rho_{milk}}\right) \times DCF_{ing} \qquad \text{(Eq. 6.1-6c)}$$

where:

$EDF_{IHI,MILKing}$	=	effective dose factor for ingestion of milk contaminated by drill cuttings (L×mrem)/(pCi×yr)
$Q_{fod,MILK}$	=	consumption rate of fodder by milk-producing livestock (kg/yr), Table 7.2-2
R_{StoV}	=	soil to vegetation ratio (unitless), Table 7.3-1
$SOIL$	=	radionuclide deposition and ((m^2×yr)/kg), as defined in Equation 3.1-3b (see Section 3.1.3)
$F_{fod,MILK}$	=	fraction of milk-producing livestock intake from field/pasture that is contaminated by drill cuttings (unitless), Table 7.2-3
PR	=	precipitation rate (m/yr), Table 7.5-1
I_{RF}	=	functional irrigation rate (m/yr) as defined by Equation 3.1-3d (see Section 3.1.2)
ER	=	evapotranspiration rate (m/yr), Table 7.5-1
TC_{MILK}	=	transfer coefficient for milk-producing livestock (yr/kg), Table 7.3-3
U_{MILK}	=	human consumption rate of milk (kg/yr), Table 7.2-1
ρ_{milk}	=	milk density (kg/L) , Table 7.2-1 (table note)
DCF_{ing}	=	dose conversion factor for ingestion (mrem/pCi), Table 7.1-1

6.1.6 Ingestion of Poultry (Chronic IHI)

The poultry and egg ingestion pathways assume poultry drink contaminated stock water and consume fodder irrigated with contaminated water. The stock water and irrigation water is from the 1-meter well. The fodder is contaminated from direct deposition of contaminated irrigation water on plants and from deposition of contaminated irrigation water in soil followed by root uptake by plants and from drill cuttings. For conservatism, it is also assumed that poultry directly ingest contaminated soil in addition to the stock water and fodder. The dose from ingestion of contaminated poultry is calculated using the following formula:

$$D_{IHIC,POULTRYing} = \left(D_{IHIC,H2OPOULTRYing} + D_{IHIC,DrillPOULTRYing}\right) \times F_{IHI,local,POULTRY} \quad \text{(Eq. 6.1-7)}$$

where:

$D_{IHIC,POULTRYing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of poultry
$D_{IHIC,H2OPOULTRYing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of poultry that has been irrigated with water from the 1-meter well
$D_{IHIC,DrillPOULTRYing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of poultry that has been contaminated by drill cuttings
$F_{IHI,local,POULTRY}$	=	fraction of consumed poultry raised locally (unitless), Table 7.6-1

The dose from ingestion of poultry contaminated by groundwater $D_{IHIC,H2OPOULTRYing}$ is calculated using the following formula:

$$D_{IHIC,H2OPOULTRYing} = C_{IHIC} \times EDF_{POULTRYing} \quad \text{(Eq. 6.1-7a)}$$

where:

$D_{IHIC,H2OPOULTRYing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of poultry that has been irrigated with water from the 1-meter well
C_{IHIC}	=	radionuclide concentration in groundwater from the 1-meter well (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{POULTRYing}$	=	effective dose factor for ingestion of poultry contaminated by groundwater (L×mrem)/(pCi×yr), as defined in Equation 3.1-7a (see Section 3.1.6)

The dose from ingestion of poultry contaminated by drill cuttings $D_{IHIC,DrillPOULTRYing}$ is calculated using the following formula:

$$D_{IHIC,DrillPOULTRYing} = C_{IHIC,g} \times EDF_{IHI,POULTRYing} \quad \text{(Eq. 6.1-7b)}$$

where:

$D_{IHIC,DrillPOULTRYing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of poultry that has been contaminated by drill cuttings
$C_{IHI,g}$	=	radionuclide concentration in the garden from contaminated drill cuttings (pCi/m^3), as defined by Equation 6.1-3c (above)
$EDF_{IHI,POULTRYing}$	=	effective dose factor for ingestion of poultry contaminated by drill cuttings (L×mrem)/(pCi×yr), as defined in Equation 6.1-7c, below

The EDF for the dose from ingestion of poultry contaminated by drill cuttings shall be calculated as:

$$EDF_{IHI,POULTRYing} = \begin{pmatrix} \left(\left(Q_{fod,POULTRY} \times \left(R_{StoV} \times SOIL\right) \times F_{fod,POULTRY}\right) \times \left(PR + I_{RF} - ER\right)\right) \\ + \left(SOIL \times I_{RF} \times Q_{SOIL,POULTRY} \times F_{SOIL,POULTRY}\right) \end{pmatrix} \times TC_{POULTRY} \times U_{POULTRY} \times DCF_{ing} \quad \text{(Eq. 6.1-7c)}$$

where:

$EDF_{IHI,POULTRYing}$	=	effective dose factor for ingestion of poultry contaminated by drill cuttings (L×mrem)/(pCi×yr)
$Q_{fod,POULTRY}$	=	consumption rate of fodder by poultry (kg/yr), Table 7.2-2
R_{StoV}	=	soil to vegetation ratio (unitless), Table 7.3-1
$SOIL$	=	radionuclide deposition and ((m^2×yr)/kg), as defined in Equation 3.1-3b (see Section 3.1.3)
$F_{fod,POULTRY}$	=	fraction of poultry intake from field/pasture that is contaminated by drill cuttings (unitless), Table 7.2-3
PR	=	precipitation rate (m/yr), Table 7.5-1
I_{RF}	=	functional irrigation rate (m/yr) as defined by Equation 3.1-3d (see Section 3.1.2)
ER	=	evapotranspiration rate (m/yr), Table 7.5-1
$SOIL$	=	radionuclide deposition and buildup rate in the soil ((m^2×yr)/kg) as defined by Equation 3.1-3b (see Section 3.1.2)
$Q_{SOIL,POULTRY}$	=	consumption rate of soil by poultry (kg/yr), Table 7.2-2
$F_{SOIL,POULTRY}$	=	fraction of poultry-soil intake from field/pasture that is contaminated by drill cuttings (unitless), Table 7.2-3
$TC_{POULTRY}$	=	transfer coefficient for poultry (yr/kg), Table 7.3-4
$U_{POULTRY}$	=	human consumption rate of poultry (kg/yr), Table 7.2-1
DCF_{ing}	=	dose conversion factor for ingestion (mrem/pCi), Table 7.1-1

6.1.7 Ingestion of Egg (Chronic IHI)

Following the poultry consumption of the contaminated water and fodder, the chronic IHI consumes the contaminated poultry and eggs. The dose from ingestion of contaminated poultry is calculated using the following formula:

$$D_{IHIC,EGGing} = \left(D_{IHIC,H2OEGGing} + D_{IHIC,DrillEGGing}\right) \times F_{IHI,local,EGG} \qquad \text{(Eq. 6.1-8)}$$

where:

$D_{IHIC,EGGing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of eggs
$D_{IHIC,H2OEGGing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of eggs that have been irrigated with water from the 1-meter well
$D_{IHIC,DrillEGGing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of eggs that have been contaminated by drill cuttings
$F_{IHI,local,EGG}$	=	fraction of consumed eggs produced locally (unitless), Table 7.6-1

The dose from ingestion of eggs contaminated by groundwater $D_{IHIC,H2OEGGing}$ is calculated using the following formula:

$$D_{IHIC,H2OEGGing} = C_{IHIC} \times EDF_{EGGing} \qquad \text{(Eq. 6.1-8a)}$$

where:

$D_{IHIC,H2OEGGing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of eggs that have been irrigated with water from the 1-meter well
C_{IHIC}	=	radionuclide concentration in groundwater from the 1-meter well (pCi/L), as determined from an appropriate contaminant transport model
EDF_{EGGing}	=	effective dose factor for ingestion of eggs contaminated by groundwater (L×mrem)/(pCi×yr), as defined in Equation 3.1-8a (see Section 3.1.7)

The dose from ingestion of eggs contaminated by drill cuttings $D_{IHIC,DrillEGGing}$ is calculated using the following formula:

$$D_{IHIC,DrillEGGing} = C_{IHIC,g} \times EDF_{IHI,EGGing} \qquad \text{(Eq. 6.1-8b)}$$

where:

$D_{IHIC,DrillEGGing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of eggs that have been contaminated by drill cuttings

$C_{IHI,g}$ = radionuclide concentration in the garden from contaminated drill cuttings (pCi/m^3), as defined by Equation 6.1-3c (above)

$EDF_{IHI,EGGing}$ = effective dose factor for ingestion of eggs contaminated by drill cuttings (L×mrem)/(pCi×yr), as defined in Equation 6.1-8c, below

The EDF for the dose from ingestion of eggs contaminated by drill cuttings shall be calculated as:

$$EDF_{IHI,EGGing} = \begin{pmatrix} \left(\left(Q_{fod,EGG} \times \left(R_{StoV} \times SOIL\right) \times F_{fod,EGG}\right) \times \left(PR + I_{RF} - ER\right)\right) \\ + \left(SOIL \times I_{RF} \times Q_{soil,EGG} \times F_{SOIL,EGG}\right) \end{pmatrix} \times TC_{EGG} \times U_{EGG} \times DCF_{ing} \qquad \text{(Eq. 6.1-8c)}$$

where:

$EDF_{IHI,EGGing}$ = effective dose factor for ingestion of eggs contaminated by drill cuttings (L×mrem)/(pCi×yr)

$Q_{fod,EGG}$ = consumption rate of fodder by eggs (kg/yr), Table 7.2-2

R_{StoV} = soil to vegetation ratio (unitless), Table 7.3-1

$SOIL$ = radionuclide deposition and ((m^2×yr)/kg), as defined in Equation 3.1-3b (see Section 3.1.3)

$F_{fod,EGG}$ = fraction of egg intake from field/pasture that is contaminated by drill cuttings (unitless), Table 7.2-3

PR = precipitation rate (m/yr), Table 7.5-1

I_{RF} = functional irrigation rate (m/yr) as defined by Equation 3.1-3d (see Section 3.1.2)

ER = evapotranspiration rate (m/yr), Table 7.5-1

$SOIL$ = radionuclide deposition and buildup rate in the soil ((m^2×yr)/kg) as defined by Equation 3.1-3b

$Q_{soil,EGG}$ = consumption rate of soil by eggs (kg/yr), Table 7.2-2

$F_{SOIL,EGG}$ = fraction of egg-soil intake from field/pasture that is contaminated with drill cuttings (unitless), Table 7.2-3

TC_{EGG} = transfer coefficient for eggs (yr/kg), Table 7.3-5

U_{EGG}	=	human consumption rate of eggs (kg/yr), Table 7.2-1
DCF_{ing}	=	dose conversion factor for ingestion (mrem/pCi), Table 7.1-1

6.1.8 Ingestion of Fish

The fish ingestion route assumes fish are caught from a contaminated stream at the point of highest concentration, and the IHI receptor in turn consumes the contaminated fish. The dose from consumption of fish shall be calculated according to Equation 3.1-9 (see Section 3.1.8).

6.2 Chronic IHI, Direct Exposure Dose Pathways

The following text defines the parameter $D_{IHIC,\exp}$ from Equation 6-1. The direct exposure dose to the chronic IHI is determined according to Equation 6.2-1:

$$D_{IHIC,\exp} = D_{IHIC,SOIL\exp} + D_{IHIC,SHOWER,\exp} + D_{SL,SWIM\exp} + D_{SL,BOAT\exp} \quad \text{(Eq. 6.2-1)}$$

where:

$D_{IHIC,\exp}$	=	dose to the chronic IHI (mrem/yr) due to exposure
$D_{IHIC,SOIL\exp}$	=	dose to chronic IHI (mrem/yr) due to direct exposure to soil contaminated by irrigation from the 1-meter well and deposition of drill cuttings
$D_{IHIC,SHOWER,\exp}$	=	dose to the chronic IHI (mrem/yr) due to direct exposure while showering or bathing in water from the 1-meter well
$D_{SL,SWIM\exp}$	=	dose to the chronic IHI (mrem/yr) due to direct exposure from swimming in stream water at the contaminated SL, as defined in Equation 3.2-4 (see Section 3.2.3)
$D_{SL,BOAT\exp}$	=	dose to the chronic IHI (mrem/yr) due to direct exposure from boating in stream water at the contaminated SL, as defined in Equation 3.2-5 (see Section 3.2.4)

Note that direct exposure from fishing at the shoreline of a contaminated stream is considered negligible relative to the other exposure pathways and is not included in this methodology.

6.2.1 Direct Exposure from Irrigated Soil (Chronic IHI)

The exposure pathway from direct contact to contaminated soil assumes the soil (1) irrigated with groundwater from a well 1 meter from the contamination source, and (2) contaminated with drill cuttings. The chronic IHI receptor is exposed during time spent caring for a garden. The radionuclide concentration in the soil and the exposure dose is calculated using the following formula:

$$D_{IHIC,SOIL\exp} = D_{IHIC,H2OSOIL\exp} + D_{IHIC,DrillSOIL\exp} \quad \text{(Eq. 6.2-2)}$$

where:

$D_{IHIC,SOIL\exp}$	=	dose to chronic IHI (mrem/yr) due to direct exposure to soil contaminated by irrigation from the 1-meter well and deposition of drill cuttings
$D_{IHIC,H2OSOIL\exp}$	=	dose to chronic IHI (mrem/yr) due to direct exposure to soil contaminated by irrigation from the 1-meter well
$D_{IHIC,DrillSOIL\exp}$	=	dose to chronic IHI (mrem/yr) due to direct exposure to soil contaminated by deposition of drill cuttings

The dose from direct exposure to soil contaminated by groundwater $D_{IHIC,H2OSOIL\exp}$ is calculated using the following formula:

$$D_{IHIC,H2OSOIL\exp} = C_{IHIC} \times EDF_{SOIL\exp} \qquad \text{(Eq. 6.2-2a)}$$

where:

$D_{IHIC,H2OSOIL\exp}$	=	dose to chronic IHI (mrem/yr) due to direct exposure to soil contaminated by irrigation from the 1-meter well
C_{IHIC}	=	radionuclide concentration in groundwater from the 1-meter well (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{SOIL\exp}$	=	effective dose factor for external exposure to soil (L×mrem)/(pCi×yr), as defined in Equation 3.2-2a (see Section 3.2.1)

The dose from direct exposure to soil contaminated by drill cuttings $D_{IHIC,DrillSOIL\exp}$ is calculated using the following formula:

$$D_{IHIC,DrillSOIL\exp} = C_{IHIC,g} \times EDF_{IHI,SOIL\exp} \qquad \text{(Eq. 6.2-2b)}$$

where:

$D_{IHIC,DrillSOIL\exp}$	=	dose to chronic IHI (mrem/yr) due to direct exposure to soil contaminated by deposition of drill cuttings
$C_{IHI,g}$	=	radionuclide concentration in the garden from contaminated drill cuttings (pCi/m^3), as defined by Equation 6.1-3c (see Section 6.1.2)
$EDF_{IHI,SOIL\exp}$	=	effective dose factor for direct exposure to soil contaminated by drill cuttings (L×mrem)/(pCi×yr), as defined in Equation 6.2-2c, below

The EDF for IHI soil exposure shall be calculated as:

$$EDF_{IHI,SOIL\exp} = DCF_{\exp} \times F_{t,g} \qquad \text{(Eq. 6.2-2c)}$$

where:

$EDF_{IHI,SOIL\exp}$ = effective dose factor for direct exposure to soil contaminated by drill cuttings (L×mrem)/(pCi×yr)

$DCF_{\exp}$ = dose conversion factor for external exposure (m^3×mrem)/(pCi×yr), Table 7.1-1

$F_{t,g}$ = fraction of the time the IHI spends in the garden (unitless), Table 7.4-1

6.2.2 Direct Exposure from Showering (Chronic IHI)

The direct contact exposure pathway from showering and bathing assumes the chronic IHI receptor receives dose from washing in water from the 1-meter well. The dose is calculated using the following formula:

$$D_{IHIC,SHOWER,\exp} = C_{IHIC} \times EDF_{SHOWER,\exp} \quad \text{(Eq. 6.2-3)}$$

where:

$D_{IHIC,SHOWER,\exp}$ = dose to the chronic IHI (mrem/yr) due to direct exposure while showering or bathing in water from the 1-meter well

C_{IHIC} = radionuclide concentration in groundwater from the 1-meter well (pCi/L), as determined from an appropriate contaminant transport model

$EDF_{SHOWER,\exp}$ = effective dose factor for external exposure to water while showering or bathing (L×mrem)/(pCi×yr), as defined in Equation 3.2-3a (see Section 3.2.2)

6.2.3 Direct Exposure from Swimming

The direct contact exposure pathway from swimming assumes the chronic IHI receptor receives dose from swimming in a contaminated stream at the point of highest concentration. The dose from swimming exposure shall be calculated according to Equation 3.2-4 (see Section 3.2.3).

6.2.4 Direct Exposure from Boating

The direct contact exposure pathway from boating assumes the chronic IHI receptor receives dose from activities in a contaminated stream at the point of highest concentration. The dose from boating exposure shall be calculated according to Equation 3.2-5 (see Section 3.2.4).

6.3 Chronic Intruder Inhalation Dose Pathways

The following text defines the parameter $D_{IHICinh}$ from Equation 6-1. The inhalation dose to the chronic IHI is determined according to Equation 6.3-1:

$$D_{IHIC,inh} = D_{IHIC,IRRinh} + D_{IHIC,DUSTinh} + D_{IHIC,SHOWERinh} + D_{SL,SWIMinh} \quad \text{(Eq. 6.3-1)}$$

where:

$D_{IHIC,inh}$ = dose to the chronic IHI (mrem/yr) due to inhalation

$D_{IHIC,IRRinh}$ = dose to the chronic IHI (mrem/yr) due to inhalation while irrigating gardens or crops with water from the 1-meter well

$D_{IHIC,DUSTinh}$ = dose to the chronic IHI (mrem/yr) due to inhalation of dust and soil that has been contaminated due to irrigation with water from the 1-meter well

$D_{IHIC,SHOWERinh}$ = dose to the chronic IHI (mrem/yr) due to inhalation while showering or bathing in water from the 1-meter well

$D_{SL,SWIMinh}$ = dose to the chronic IHI (mrem/yr) due to inhalation while swimming in stream water at the contaminated SL , as defined in Equation 3.3-5 (see Section 3.3.4)

6.3.1 Inhalation of Water during Irrigation (Chronic IHI)

The exposure pathway from inhalation during irrigation assumes soil is irrigated with groundwater from the 1-meter well and the chronic IHI receptor is exposed by breathing while the garden is irrigated but only during time spent caring for a garden. The dose is calculated using the following formula:

$$D_{IHIC,IRRinh} = C_{IHIC} \times EDF_{IRRinh} \quad \text{(Eq. 6.3-2)}$$

where:

$D_{IHIC,IRRinh}$ = dose to the chronic IHI (mrem/yr) due to inhalation while irrigating gardens or crops with water from the 1-meter well

C_{IHIC} = radionuclide concentration in groundwater from the 1-meter well (pCi/L), as determined from an appropriate contaminant transport model

EDF_{IRRinh} = effective dose factor for inhalation of water during irrigation (L×mrem)/(pCi×yr), as defined in Equation 3.3-2a (see Section 3.3.1)

6.3.2 Inhalation of Dust from Irrigated Soil (Chronic IHI)

The dose pathway associated with inhalation of dust and soil that has been irrigated assumes that dust and soil has been irrigated with water from the 1-meter well and includes drill cuttings. The chronic IHI receptor is exposed by breathing dust during time spent caring for a garden. This formula was derived following the approach of previous pathway calculations. The dose is calculated using the following formula:

$$D_{IHIC,DUSTinh} = D_{IHIC,H2ODUSTinh} + D_{IHIC,DrillDUSTinh} \qquad \text{(Eq. 6.3-3)}$$

where:

$D_{IHIC,DUSTinh}$ = dose to the chronic IHI (mrem/yr) due to inhalation of dust and soil that has been contaminated due to irrigation with water from the 1-meter well and from deposition of drill cuttings

$D_{IHIC,H2ODUSTinh}$ = dose to the chronic IHI (mrem/yr) due to inhalation of dust and soil that has been contaminated due to irrigation with water from the 1-meter well

$D_{IHIC,DrillDUSTinh}$ = dose to the chronic IHI (mrem/yr) due to inhalation of dust and soil that has been contaminated from deposition of drill cuttings

The dose from direct exposure to soil contaminated by groundwater $D_{IHIC,H2ODUSTinh}$ is calculated using the following formula:

$$D_{IHIC,H2ODUSTinh} = C_{IHIC} \times EDF_{DUSTinh} \qquad \text{(Eq. 6.3-3a)}$$

where:

$D_{IHIC,H2ODUSTinh}$ = dose to chronic IHI (mrem/yr) due to inhalation of dust and soil that has been contaminated due to irrigation with water from the 1-meter well

C_{IHIC} = radionuclide concentration in groundwater from the 1-meter well (pCi/L), as determined from an appropriate contaminant transport model

$EDF_{DUSTinh}$ = effective dose factor for inhalation of dust and soil (L×mrem)/(pCi×yr), as defined in Equation 3.3-3a (see Section 3.3.2)

The dose from direct exposure to soil contaminated by drill cuttings $D_{IHIC,DrillDUSTinh}$ is calculated using the following formula:

$$D_{IHIC,DUSTinh} = C_{IHI,g} \times EDF_{IHIC,inh} \qquad \text{(Eq. 6.3-3b)}$$

where:

$D_{IHIC,DrillDUSTinh}$ = dose to the chronic IHI (mrem/yr) due to inhalation of dust and soil that has been contaminated from deposition of drill cuttings

$C_{IHI,g}$	=	radionuclide concentration in the garden from contaminated drill cuttings (pCi/m^3), as defined by Equation 6.1-3c (see Section 6.1.2)
$EDF_{IHIC,inh}$	=	effective dose factor for inhalation of dust from contaminated drill cuttings (L×mrem)/(pCi×yr), as defined in Equation 6.3-3c, below

The EDF for inhalation of dust from drill cuttings shall be calculated as:

$$EDF_{IHIC,inh} = \frac{F_{t,d} \times L_{soil} \times U_{air} \times DCF_{inh}}{\rho_s} \qquad \text{(Eq. 6.3-3c)}$$

where:

$EDF_{IHIC,inh}$	=	effective dose factor for inhalation of dust from contaminated drill cuttings (L×mrem)/(pCi×yr)
$F_{t,d}$	=	fraction of time exposed to drill cuttings (unitless), Table 7.4-1
L_{soil}	=	soil loading in air while working in a garden (kg/m^3), Table 7.4-1
U_{air}	=	air intake (m^3/yr), Table 7.2-1
DCF_{inh}	=	dose conversion factor for inhalation (mrem/pCi), Table 7.1-1
ρ_S	=	dry bulk density of soil (kg/m^3), Table 7.5-1

6.3.3 Inhalation during Showering (Chronic IHI)

The showering inhalation dose pathway assumes the chronic IHI receptor is exposed by breathing humid air within the shower. The source of water for the shower is a well 1-meter from the contamination source. The dose is calculated using the following formula:

$$D_{IHIC,SHOWERinh} = C_{IHIC} \times EDF_{SHOWERinh} \qquad \text{(Eq. 6.3-4)}$$

where:

$D_{IHIC,SHOWERinh}$	=	dose to the chronic IHI (mrem/yr) due to inhalation while showering or bathing in water from the 1-meter well
C_{IHIC}	=	radionuclide concentration in groundwater from the 1-meter well (pCi/L), as determined from an appropriate contaminant transport model
$EDF_{SHOWERinh}$	=	effective dose factor for inhalation of water while showering or bathing (L×mrem)/(pCi×yr), as defined in Equation 3.3-4a (see Section 3.3.3)

6.3.4 Inhalation during Swimming

The swimming inhalation pathway assumes that water from a stream has been contaminated by groundwater and that the receptor inhales saturated air. For simplicity and conservatism, the amount of moisture contained in the inhaled air is assumed to be groundwater. The dose is calculated using Equation 3.3-5 (see Section 3.3.4).

7.0 PARAMETERS

The following provides recommended values based on practices at the Savannah River Site, current literature reviews, and derivations as described herein.

7.1 Dose Conversion Factors

The purpose of this section is to present a set of DCFs for use in dose calculations for the Liquid Waste PAs and related modeling efforts. A comprehensive list of DCFs was prepared and included below. Note that due to approaches to screening radionuclide inventories and other factors, PAs and other models may only use a subset of the values listed.

Radiation doses to the human receptors (MOP or IHI) may result from internal intake of radionuclides by ingestion, inhalation, or from external exposure to radionuclides present in the environment. The dose calculations described earlier use DCFs to convert exposure to dose.

Previous PA analyses used the DCFs from the International Commission on Radiological Protection (ICRP) Publication 72, published in 1996, and the EPA Federal Guidance Report 11, published in 1988. [ICRP-72; EPA-520-1-88-020] The recommended values have been revised to reflect newer guidance from updated data sources. Specifically, the DCFs for ingestion and inhalation come from the DOE's Derived Concentration Technical Standard, Tables A-1 and A-2, respectively, of a 2011 Technical Standard Report; and the DCF's for soil and water exposure come from a revised input data set for special software associated with the EPA's Federal Guidance Reports 12 and 13 (DCPAK3.02, data files: FGR12III2.DAT and FGR12III6.DAT). [DOE-STD-1196-2011, EPA-402-R-93-081, EPA-402-R-99-001]

The ingestion and inhalation DCFs from DOE's Derived Concentration Technical Standard are converted to standard units for input into the calculations by multiplying the DCFs by 3.7E+03 (mrem/pCi)/(Sv/Bq). [DOE-STD-1196-2011] These internal DCFs are expressed in millirem divided by picocurie (mrem/pCi) and presented in Table 7.1-1 for the various radionuclides. The calculations presented in Sections 3 through 6 assume the receptor (MOP or IHI) is an age- and gender- weighted Reference Person, as consistent with guidance in DOE's Derived Concentration Technical Standard. [DOE-STD-1196-2011] In accordance with this assumption, the values shown in Table 7.1-1 apply internal DCFs for the Reference Individual (i.e., a demographic composite of individuals of all ages)

External DCFs for soil exposure assume that contaminated soil is uniformly distributed at a depth of 0.15 m. The values associated with EPA Federal Guidance Report 12 show the dose rate per unit of activity of contaminated media, reported in Sieverts per second divided by Becquerels per meter cubed (Sv/s)/(Bq/m^3). [EPA-402-R-93-081] The DCFs are converted to standard units for input into PA calculations by multiplying the EPA-402-R-93-081 DCFs by 3.7E+03 (mrem/pCi)/(Sv/Bq) and by 31,557,600 (s/yr), resulting in units of (m^3×mrem)/(pCi×yr). External DCFs are presented in Table 7.1-1 for both contaminated soil and for immersion in contaminated water.

DCFs from short-lived progeny may be combined with those from the longer-lived parents as a modeling simplification. Models make use of this simplification by assuming that the selected daughter products are in secular equilibrium with the parent radionuclides. The equilibrium is

calculated using the individual DCFs, adjusted by the branching fraction for the daughter products to the parent. For example, the ingestion DCFs for Am-242m at secular equilibrium include:

- Am-242m (7.99E-04 mrem/pCi) with no branching fraction (7.99E-04 mrem/pCi),
- Am-242 (1.56E-06 mrem/pCi) with a branching fraction of 0.996 (1.56E-06 mrem/pCi × 0.996 = 1.56E-06 mrem/pCi),
- Np-238 (4.44E-06 mrem/pCi) with a branching fraction of 0.004 (4.44E-06 mrem/pCi × 0.004 = 1.78E-08 mrem/pCi, and
- Cm-242 (7.10E-05 mrem/pCi) with a branching fraction of 0.827 (7.10E-05 mrem/pCi × 0.004 = 5.88E-05 mrem/pCi)

Therefore, the ingestion DCFs for Am-242m at secular equilibrium is 7.99E-04 mrem/pCi + 1.56E-06 mrem/pCi + 1.78E-08 mrem/pCi + 5.88E-05 mrem/pCi = 8.60E-04 mrem/pCi.

Due to these secular equilibrium adjustments, Table 7.1-1 shows duplicate entries for some DCFs where the first entry is the DCF for the specific radionuclide and the second entry (shaded) represents the sum of the parent and its progeny that are assumed to be in secular equilibrium. Table 7.1-2 provides a summary which radionuclides are assumed to be in secular equilibrium with their daughter products (i.e., those that are shaded in Table 7.1-1).

Table 7.1-1: Internal and External DCFs

Nuclide	Internal DCFs (mrem/pCi)		External DCFs (m^3×mrem)/(pCi×yr)	
	Ingestion	Inhalation	Soil Exposure (assumes 0.15 m depth)	Water Immersion
	DCF_{ing}	DCF_{inh}	$DCF_{\exp}$	DCF_{imm}
Ac-225	1.94E-04	3.77E-03	3.21E-08	1.47E-07
Ac-227	1.45E-03	5.96E-01	1.61E-10	9.63E-10
Ac-227 [a]	2.31E-03	6.00E-01	1.21E-06	4.85E-06
Ac-228	1.90E-06	5.03E-05	2.72E-06	1.01E-05
Ag-108m	1.09E-05	2.59E-05	5.03E-06	1.83E-05
Al-26	1.70E-05	4.85E-05	8.58E-06	3.25E-05
Am-241	8.81E-04	3.63E-01	2.32E-08	1.80E-07
Am-242	1.56E-06	4.96E-05	2.80E-08	1.48E-07
Am-242m	7.99E-04	3.43E-01	6.59E-10	5.29E-09
Am-242m [a]	8.60E-04	3.55E-01	3.61E-08	1.81E-07
Am-243	8.73E-04	3.61E-01	8.03E-08	5.07E-07
Am-243 [a]	8.77E-04	3.61E-01	5.19E-07	2.40E-06
Ar-39	0.00E+00	0.00E+00	4.96E-10	1.49E-08
At-217	0.00E+00	0.00E+00	6.94E-10	2.70E-09
At-218	0.00E+00	0.00E+00	3.34E-11	1.46E-10
Ba-133	9.03E-06	7.62E-06	1.07E-06	4.16E-06
Ba-137m	0.00E+00	0.00E+00	1.88E-06	6.81E-06
Bi-210	6.66E-06	4.77E-06	3.35E-09	3.48E-08

Table 7.1-1: Internal and External DCFs (Continued)

Nuclide	Internal DCFs (mrem/pCi)		External DCFs (m^3×mrem)/(pCi×yr)	
	Ingestion	Inhalation	Soil Exposure (assumes 0.15 m depth)	Water Immersion
	DCF_{ing}	DCF_{inh}	DCF_{exp}	DCF_{imm}
Bi-210m	7.44E-05	2.01E-04	7.62E-07	2.91E-06
Bi-210m [a]	7.44E-05	2.01E-04	7.70E-07	2.96E-06
Bi-211	0.00E+00	0.00E+00	1.40E-07	5.27E-07
Bi-212	1.30E-06	3.81E-05	3.37E-07	1.26E-06
Bi-213	9.92E-07	4.44E-05	3.93E-07	1.47E-06
Bi-214	5.51E-07	3.05E-05	4.76E-06	1.80E-05
Bk-249	4.63E-06	1.63E-03	3.85E-12	6.33E-11
C-14	2.34E-06	8.07E-07	6.91E-12	3.37E-10
Ca-41	1.10E-06	8.47E-07	0.00E+00	0.00E+00
Cd-113m	9.51E-05	4.33E-04	5.46E-10	1.24E-08
Ce-144	2.68E-05	1.81E-04	3.91E-08	1.88E-07
Cf-249	1.65E-03	6.59E-01	9.80E-07	3.63E-06
Cf-250	8.21E-04	3.04E-01	3.14E-08	1.21E-07
Cf-251	1.68E-03	6.70E-01	2.83E-07	1.25E-06
Cf-252	5.59E-04	1.64E-01	1.46E-06	5.62E-06
Cl-36	4.59E-06	1.52E-06	1.46E-09	2.27E-08
Cm-242	7.10E-05	1.46E-02	7.93E-11	1.06E-09
Cm-243	6.66E-04	2.65E-01	3.25E-07	1.37E-06
Cm-244	5.59E-04	2.18E-01	1.13E-10	1.08E-09
Cm-245	8.95E-04	3.70E-01	2.18E-07	1.04E-06
Cm-246	8.92E-04	3.70E-01	1.16E-08	4.52E-08
Cm-247	8.21E-04	3.39E-01	9.55E-07	3.51E-06
Cm-247 [a]	8.22E-04	3.39E-01	9.99E-07	3.76E-06
Cm-248	3.34E-03	1.36E+00	4.19E-06	1.62E-05
Co-60	2.03E-05	2.23E-05	8.07E-06	3.01E-05
Cs-134	6.92E-05	2.43E-05	4.92E-06	1.79E-05
Cs-135	9.77E-06	3.38E-06	4.88E-11	2.77E-09
Cs-137	4.92E-05	1.70E-05	5.34E-10	1.23E-08
Cs-137 [a]	4.92E-05	1.70E-05	1.78E-06	6.44E-06
Eu-152	6.44E-06	3.67E-04	3.63E-06	1.37E-05
Eu-154	9.66E-06	4.26E-04	3.92E-06	1.46E-05
Eu-155	1.67E-06	5.11E-05	1.02E-07	5.69E-07
Fr-221	0.00E+00	0.00E+00	8.01E-08	3.21E-07
Fr-223	1.20E-05	4.18E-06	1.04E-07	5.31E-07
Gd-152	1.97E-04	7.44E-02	0.00E+00	0.00E+00
H-3	7.77E-08	2.47E-08	0.00E+00	0.00E+00
I-129	4.48E-04	1.50E-04	6.06E-09	7.80E-08
K-40	3.04E-05	9.55E-06	5.14E-07	1.96E-06
Kr-85	0.00E+00	0.00E+00	7.79E-09	4.38E-08
Lu-174	1.42E-06	3.00E-05	2.55E-07	1.15E-06
Mo-93	1.15E-05	3.65E-06	2.56E-10	4.66E-09
Mo-93m	5.44E-07	4.63E-07	7.39E-06	2.76E-05
Na-22	1.44E-05	5.59E-06	6.97E-06	2.57E-05
Nb-93m	6.59E-07	1.03E-06	4.57E-11	8.33E-10

Table 7.1-1: Internal and External DCFs (Continued)

Nuclide	Internal DCFs (mrem/pCi)		External DCFs (m^3×mrem)/(pCi×yr)	
	Ingestion	Inhalation	Soil Exposure (assumes 0.15 m depth)	Water Immersion
	DCF_{ing}	DCF_{inh}	$DCF_{\exp}$	DCF_{imm}
Nb-94	8.25E-06	2.46E-05	4.95E-06	1.81E-05
Ni-59	2.95E-07	7.47E-07	4.83E-11	1.75E-10
Ni-63	7.33E-07	1.84E-06	0.00E+00	0.00E+00
Np-237	4.63E-04	1.87E-01	4.18E-08	2.25E-07
Np-237 [a]	4.67E-04	1.87E-01	6.44E-07	2.60E-06
Np-238	4.44E-06	1.32E-05	1.86E-06	6.87E-06
Np-239	4.11E-06	8.33E-07	4.39E-07	1.89E-06
Np-240	3.55E-07	1.46E-07	3.22E-06	1.20E-05
Np-240m	0.00E+00	0.00E+00	1.01E-06	3.74E-06
Pa-231	2.07E-03	8.77E-01	9.49E-08	3.71E-07
Pa-233	4.88E-06	5.29E-06	6.02E-07	2.37E-06
Pa-234	2.06E-06	6.03E-07	4.53E-06	1.69E-05
Pa-234m	0.00E+00	0.00E+00	6.96E-08	2.86E-07
Pb-209	2.76E-07	7.73E-08	4.64E-10	1.31E-08
Pb-210	3.77E-03	3.74E-03	1.31E-09	1.27E-08
Pb-210 [a]	1.03E-02	6.57E-03	4.69E-09	4.76E-08
Pb-211	9.69E-07	1.62E-05	2.06E-07	7.80E-07
Pb-212	3.81E-05	8.07E-05	3.78E-07	1.56E-06
Pb-214	7.36E-07	1.24E-05	7.34E-07	2.81E-06
Pd-107	1.96E-07	1.19E-07	0.00E+00	0.00E+00
Pm-147	1.34E-06	2.95E-05	2.69E-11	1.13E-09
Po-210	6.48E-03	2.83E-03	3.08E-11	1.13E-10
Po-211	0.00E+00	0.00E+00	2.58E-08	9.43E-08
Po-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-213	0.00E+00	0.00E+00	1.19E-10	4.33E-10
Po-214	0.00E+00	0.00E+00	2.64E-10	9.61E-10
Po-215	0.00E+00	0.00E+00	5.42E-10	1.98E-09
Po-216	0.00E+00	0.00E+00	4.86E-11	1.77E-10
Po-218	0.00E+00	0.00E+00	5.77E-15	3.34E-13
Pr-144	2.52E-07	4.70E-08	1.32E-07	5.20E-07
Pt-193	1.82E-07	1.06E-07	2.73E-12	7.67E-11
Pu-238	9.73E-04	4.07E-01	6.94E-11	9.12E-10
Pu-239	1.07E-03	4.48E-01	1.67E-10	9.94E-10
Pu-240	1.07E-03	4.48E-01	7.01E-11	8.94E-10
Pu-241	1.93E-05	8.51E-03	3.26E-12	1.60E-11
Pu-242	1.01E-03	4.26E-01	2.99E-10	1.67E-09
Pu-243	4.33E-07	1.39E-07	4.40E-08	2.43E-07
Pu-244	1.01E-03	4.18E-01	6.33E-08	2.44E-07
Pu-244 [a]	1.02E-03	4.18E-01	1.08E-06	4.03E-06
Ra-223	8.03E-04	6.77E-04	3.47E-07	1.48E-06
Ra-224	4.66E-04	3.96E-04	2.97E-08	1.15E-07
Ra-225	8.81E-04	7.40E-04	5.57E-09	6.34E-08
Ra-226	1.68E-03	1.72E-03	1.94E-08	7.99E-08
Ra-226 [a]	1.68E-03	1.77E-03	5.52E-06	2.09E-05

Table 7.1-1: Internal and External DCFs (Continued)

Nuclide	Internal DCFs (mrem/pCi)		External DCFs $(m^3 \times mrem)/(pCi \times yr)$	
	Ingestion	Inhalation	Soil Exposure (assumes 0.15 m depth)	Water Immersion
	DCF_{ing}	DCF_{inh}	DCF_{exp}	DCF_{imm}
Ra-228	5.92E-03	5.44E-03	4.11E-11	7.92E-10
Ra-228 [a]	6.86E-03	1.33E-01	7.34E-06	2.84E-05
Rb-87	7.59E-06	2.39E-06	8.41E-11	4.55E-09
Re-188	7.10E-06	2.22E-06	1.89E-07	7.71E-07
Rh-106	0.00E+00	0.00E+00	7.01E-07	2.57E-06
Rn-219	0.00E+00	0.00E+00	1.74E-07	6.54E-07
Rn-220	0.00E+00	0.00E+00	1.96E-09	7.12E-09
Ru-106	3.55E-05	3.58E-05	0.00E+00	0.00E+00
S-35	6.44E-07	2.35E-07	7.62E-12	3.97E-10
Sb-125	5.44E-06	6.03E-06	1.31E-06	4.81E-06
Sb-126	1.29E-05	4.81E-06	8.69E-06	3.16E-05
Sb-126m	1.85E-07	5.59E-08	4.87E-06	1.77E-05
Sc-46	6.96E-06	2.81E-05	6.42E-06	2.37E-05
Se-79	1.73E-05	6.22E-06	7.97E-12	3.95E-10
Sm-147	2.37E-04	9.03E-02	0.00E+00	0.00E+00
Sm-151	5.00E-07	3.64E-05	4.53E-13	7.24E-12
Sn-121	1.17E-06	2.83E-07	1.10E-10	5.09E-09
Sn-121m	1.96E-06	3.62E-06	9.04E-10	1.31E-08
Sn-126	2.36E-05	4.92E-05	8.15E-08	4.78E-07
Sn-126 [a]	2.56E-05	4.99E-05	6.17E-06	2.27E-05
Sr-90	1.33E-04	1.02E-04	3.99E-10	1.27E-08
Sr-90 [a]	1.47E-04	1.05E-04	2.46E-08	1.28E-07
Tc-99	3.33E-06	1.34E-06	6.88E-11	3.67E-09
Te-125m	4.51E-06	2.38E-06	6.95E-09	9.08E-08
Th-227	5.44E-05	3.20E-03	3.36E-07	1.34E-06
Th-228	4.29E-04	1.27E-01	4.45E-09	2.15E-08
Th-229	2.25E-03	9.21E-01	1.77E-07	8.64E-07
Th-229 [a]	3.33E-03	9.26E-01	8.31E-07	3.42E-06
Th-230	9.36E-04	3.85E-01	6.82E-10	3.99E-09
Th-231	1.71E-06	3.64E-07	2.03E-08	1.19E-07
Th-232	1.03E-03	4.26E-01	2.98E-10	2.10E-09
Th-234	1.73E-05	1.23E-05	1.45E-08	8.43E-08
Tl-207	0.00E+00	0.00E+00	1.37E-08	7.59E-08
Tl-208	0.00E+00	0.00E+00	1.08E-05	4.25E-05
Tl-209	0.00E+00	0.00E+00	6.76E-06	2.57E-05
U-232	1.49E-03	1.71E-02	4.46E-10	2.84E-09
U-232 [a]	2.43E-03	1.44E-01	4.62E-06	1.82E-05
U-233	2.23E-04	2.36E-03	5.56E-10	2.74E-09
U-234	2.15E-04	2.28E-03	2.15E-10	1.63E-09
U-235	2.03E-04	2.12E-03	4.26E-07	1.76E-06
U-235 [a]	2.05E-04	2.12E-03	4.47E-07	1.88E-06
U-236	2.02E-04	2.14E-03	1.10E-10	1.01E-09
U-238	1.94E-04	2.05E-03	1.01E-10	8.55E-10
U-238 [a]	2.13E-04	2.06E-03	4.61E-06	1.73E-05

Table 7.1-1: Internal and External DCFs (Continued)

Nuclide	Internal DCFs (mrem/pCi)		External DCFs (m^3×mrem)/(pCi×yr)	
	Ingestion	Inhalation	Soil Exposure (assumes 0.15 m depth)	Water Immersion
	DCF_{ing}	DCF_{inh}	DCF_{exp}	DCF_{imm}
U-240	5.55E-06	9.25E-07	9.25E-09	5.02E-08
W-181	4.18E-07	1.35E-07	4.00E-08	3.07E-07
W-185	2.24E-06	5.48E-07	2.29E-10	6.62E-09
W-188	1.05E-05	2.68E-06	5.29E-09	2.43E-08
Y-90	1.37E-05	2.59E-06	2.42E-08	1.15E-07
Zr-93	3.70E-06	8.14E-05	0.00E+00	7.88E-14

Sources: DOE-STD-1196-2011, Tables A-1 and A2; EPA's Special Software: DCPAK3.02, files FGR12III2.DAT and FGR12III6.DAT.

a Value shows the sum of a parent radionuclide plus daughter products assumed to be at secular equilibrium. See Table 7.1-2 for a summary of which radionuclides were used in this assumption.
Also, note that Appendix B provides additional Internal DCFs for Infant, Child, and Adult age groups.

Table 7.1-2: Radionuclides Assumed to be in Secular Equilibrium for Liquid Waste PAs

Original Parent Radionuclide	Daughters Assumed at Equilibrium
Ac-227	Th-227
	Fr-223
	Ra-223
	Rn-219
	Po-215
	Pb-211
	Bi-211
	Tl-207
	Po-211
Am-242m	Am-242
	Np-238
	Cm-242
Am-243	Np-239
Bi-210m	Tl-206
Cm-247	Pu-243
Cs-137	Ba-137m
Np-237	Pa-233
Pb-210	Bi-210
	Po-210
Pu-244	U-240
	Np-240m

Original Parent Radionuclide	Daughters Assumed at Equilibrium
Ra-226	Rn-222
	Po-218
	Pb-214
	At-218
	Bi-214
	Po-214
Ra-228	Ac-228
	Th-228
	Ra-224
	Rn-220
	Po-216
	Pb-212
	Bi-212
	Po-212
	Tl-208
Sn-126	Sb-126m
	Sb-126
Sr-90	Y-90

Original Parent Radionuclide	Daughters Assumed at Equilibrium
Th-229	Ra-225
	Ac-225
	Fr-221
	At-217
	Bi-213
	Po-213
	Tl-209
	Pb-209
U-232	Th-228
	Ra-224
	Rn-220
	Po-216
	Pb-212
	Bi-212
	Po-212
	Tl-208
U-235	Th-231
U-238	Th-234
	Pa-234m
	Pa-234

7.2 Uptake Parameters

Uptake parameters are used to define rates of uptake for food consumption, drink consumption, and air inhalation. Section 7.2.1 provides the uptake factors that are specific to human uptake. Section 7.2.2 provides the uptake factors for other receptors (e.g., meat and poultry) that affect human receptors through food chain interaction.

7.2.1 Human Uptake Parameters

The following describes the human uptake parameters. These parameters are used to define the rates of consumption and breathing. Table 7.2-1 provides a summary of the human uptake parameters recommended for dose modeling. These human uptake parameters were all developed based on the EPA's *Exposure Factors Handbook*, as described in Appendix B. [EPA-600-R-090-052F] Note that these parameters assume that the MOP and IHI receptors are age- and gender- weighted.

Table 7.2-1: Human Uptake Parameters

Parameter	Symbol in Equations	Unit	Value [a]	Probabilistic Multiplier				
				Distribution	Mean/ Mode	SD	Min	Max
rate of water consumption[b]	$U_{H2O} \times F_{local,H2O}$	L/yr	340	Gamma	1.2	0.8	0.26	2.3
	U_{H2O}		439					
rate of soil and dust consumption	U_{SOIL}	kg/yr	3.65E-02	Triangular	1.0	N/A	0.5	2.0
rate of produce consumption	U_P	kg/yr	132	Log-Normal	0.9[d]	2.6[d]	0.2	3.07
rate of meat consumption	U_{MEAT}	kg/yr	61.4	Gamma	1.0	0.69	0.29	1.88
rate of milk consumption	U_{MILK}	kg/yr[c]	86	Gamma	1.0	0.94	0.16	2.16
rate of poultry consumption	$U_{POULTRY}$	kg/yr	10.6	N/A	N/A	N/A	N/A	N/A
rate of egg consumption	U_{EGG}	kg/yr	7.3	N/A	N/A	N/A	N/A	N/A
rate of fish consumption	U_{FISH}	kg/yr	5.6	Log-Normal	1.0[d]	2.3[d]	0.33	2.93
human breathing rate	U_{air}	m^3/yr	5,844	Gamma	1.0	0.23	0.77	1.27

a This is the recommended value, for use in deterministic modeling.

b Two values are provided for water consumption. The first value represents water that the MOP consumes from a contaminated source (i.e., with the local fraction already included); whereas the second value represents an alternative water value indicative of the total water (i.e., from all sources) consumed. The first value is the recommended value for use in modeling. The second value is provided for completeness.

c For use in dose calculations, this value must be converted to L/yr by dividing the rate of milk consumption by the density of milk (ρ_{milk}), which is assumed to be 1.03 kg/L. [Section 2.2 of ORNL-5786]

d Use geometric means and standard deviations for these parameters.

SD = standard deviation

N/A = Not Applicable

The distributions for these human uptake factors are designed to be implemented as multiplication factors within the model. Although the mean values are not always 1.0, for deterministic modeling a value of 1.0 should always be used.

7.2.2 Other Uptake Parameters

The following describes the recommended uptake parameters for animal and livestock uptake. These parameters are used to define the rates of biotic accumulation within livestock (or biotic receptors) prior to being consumed by human receptors. Table 7.2-2 provides a summary of these uptake parameters. The notes associated with this table indicate the sources for these parameter values. Poultry and egg are assumed to be minor dose contributors, relative to meat and milk; therefore, as a modeling simplification conservative values are assumed and no probability sampling is recommended for the poultry and egg parameters. These uncertainty distributions are designed to be applied as multiplication factors.

Table 7.2-2: Other Uptake Parameters

Parameter	Symbol in Equations	Unit [a]	Value [b]	Probabilistic Multiplier			
				Distribution	Mode	Min	Max
consumption of water by terrestrial livestock	$Q_{H2O,MEAT}$	L/yr	1.02E+04[c]	Triangular	1.0	1.0	1.8
consumption of fodder by terrestrial livestock	$Q_{fod,MEAT}$	kg/yr	1.31E+04[c]	Triangular	1.0	0.75	1.4
consumption of water by milk cows	$Q_{H2O,MILK}$	L/yr	1.83E+04[c]	Triangular	1.0	1.0	1.2
consumption of fodder by milk cows	$Q_{fod,MILK}$	kg/yr	1.9E+04[c]	Triangular	1.0	0.69	1.1
consumption of water by poultry	$Q_{H2O,POULTRY}$	L/yr	1.10E+02[d]	N/A	N/A	N/A	N/A
consumption of fodder by poultry	$Q_{fod,POULTRY}$	kg/yr	3.65E+01[d]	N/A	N/A	N/A	N/A
consumption of soil by poultry	$Q_{SOIL,POULTRY}$	kg/yr	3.65E+00[d]	N/A	N/A	N/A	N/A
consumption of water by egg-producers	$Q_{H2O,EGG}$	L/yr	1.10E+02[d]	N/A	N/A	N/A	N/A
consumption of fodder by egg-producers	$Q_{fod,EGG}$	kg/yr	3.65E+01[d]	N/A	N/A	N/A	N/A
consumption of soil by egg-producers	$Q_{SOIL,EGG}$	kg/yr	3.65E+00[d]	N/A	N/A	N/A	N/A

a Values in this table were converted from per day values (in the cited references) to per year values by multiplying 365.25 days/yr.
b This is the recommended value, for use in deterministic modeling.
c WSRC-STI-2007-00004, Rev. 4, Table 4-1
d ML083190829, Table A-1
SD = standard deviation
N/A = Not Applicable

The uptake parameters in Table 7.2-2 are contingent on the behavior and location of the biotic receptor. For example, if a cow grazes half the time at a field that has not been contaminated, it would not accumulate as much contaminants as a cow that only grazes in a contaminated field. Therefore, fractions are associated with some of the uptake values. These fractional values are presented in Table 7.2-3.

Table 7.2-3: Uptake Fractions for Biotic Receptors

Parameter	Symbol in Equations	Value [a]	Probabilistic Multiplier			
			Distribution	Mode	Min	Max
fraction of fodder (consumed by terrestrial livestock) that is contaminated	$F_{fod,MEAT}$	0.75[b]	Triangular	1.0	0.67	1.33
fraction of fodder (consumed by milk-producing livestock) that is contaminated consumption	$F_{fod,MILK}$	0.56[b]	Triangular	1.0	0.89	1.8
fraction of fodder (consumed by poultry) that is contaminated	$F_{fod,POULTRY}$	1.0[c]	N/A	N/A	N/A	N/A
fraction of soil (consumed by poultry) that is contaminated	$F_{SOIL,POULTRY}$	1.0[c]	N/A	N/A	N/A	N/A
fraction of fodder (consumed by egg-producers) that is contaminated	$F_{fod,EGG}$	1.0[c]	N/A	N/A	N/A	N/A
fraction of soil (consumed by egg-producers) that is contaminated	$F_{SOIL,EGG}$	1.0[c]	N/A	N/A	N/A	N/A

a This is the recommended value, for use in deterministic modeling.
b WSRC-STI-2007-00004, Rev. 4, Table 4-1
c Conservative assumption.

Note that there is no fraction for contaminated water identified in the equations in Sections 3 through 6. It is conservatively assumed that all of the water consumed by biotic receptors has been contaminated (i.e., no fraction is needed). The uncertainty distributions are designed to be applied as multiplication factors.

7.3 Transfer Coefficients for Biotic Accumulation

PA analyses at the Savannah River Site use transfer coefficients (or transfer factors) to calculate biotic accumulation of contaminants in various media. These include soil-to-plant (also known as soil-to-vegetable ratios), feed-to-meat, feed-to-milk, feed-to-poultry, feed-to-egg, and water-to-fish.

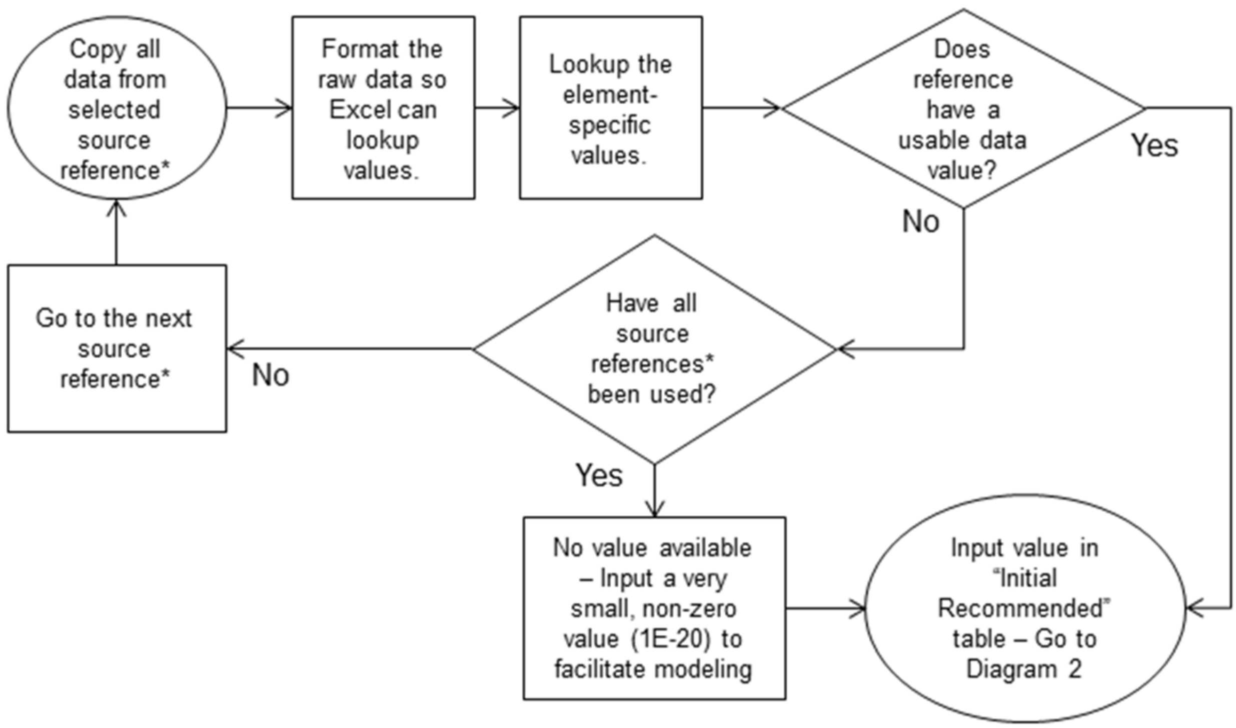
The soil-to-plant transfer coefficients determine the fraction of the available contaminant mass that is drawn from the soil into the edible plant. Feed-to-meat transfer coefficients represent the element-specific fraction transferred from fodder to meat. Feed-to-milk transfer coefficients represent the element-specific fraction transferred from fodder to milk. Water-to-fish transfer coefficients are the equilibrium ratios between concentration in finfish and concentration in water. Feed-to-poultry transfer coefficients represent the element-specific fraction transferred from fodder to poultry. Feed-to-egg transfer coefficients represent the element-specific fraction transferred from fodder to eggs.

The factors used were developed based on comparison to a number of other DOE facilities and other references (identified below) to establish relevance of the parameters selected and, as needed, to verify the regional differences for the Southeastern United States.

In the current Liquid Waste PAs, a number of these transfer coefficients were probabilistically sampled using a triangular distribution curve. However, Section 5.6.4.3.4 of the HTF PA Rev. 1 indicated that this distribution is unrealistic and has a significant impact when sampled at the high end. [SRR-CWDA-2010-00128] Therefore, the probability distributions were analyzed to develop a different (i.e., more realistic) approach to sampling for these parameters, as described below.

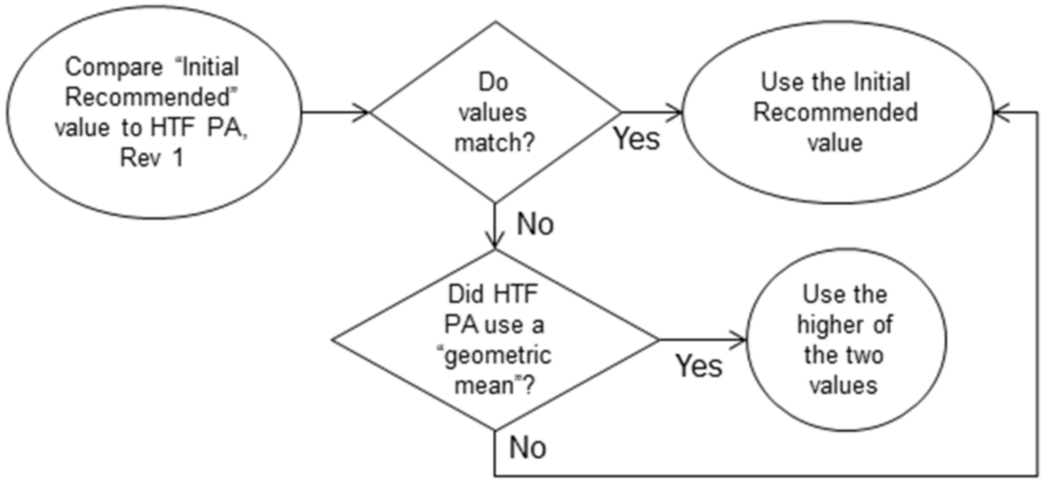
The transfer coefficients recommended for PA modeling are provided below. The data in these tables was taken from IAEA-472, PNNL-13421, ORNL-5786, NUREG_CR-5512, WSRC-STI-2007-00004, and SRR-CWDA-2010-00128. Figures 7.3-1 and 7.3-2 outline the process used in developing this data.

Figure 7.3-1: Transfer Coefficient Data Development, Diagram 1



* The source references were assigned a set hierarchy so that the data development would be internally consistent. The order of this hierarchy is as follows: (1) IAEA-472, (2) PNNL-13421, (3) ORNL-5786, (4), NUREG_CR-5512, (5) WSRC-STI-2007-00004, Rev. 4, and (6) HTF PA, Rev. 1.

Figure 7.3-2: Transfer Coefficient Data Development, Diagram 2



7.3.1 Soil-to-Plant Transfer Coefficients

Table 7.3-1 provides a listing of the recommended transfer coefficients for the soil-to-plant biotic accumulation (R_{StoV}). These values were developed using data from IAEA-472, PNNL-13421, ORNL-5786, NUREG_CR-5512, WSRC-STI-2007-00004, and SRR-CWDA-2010-00128. When wet-weight values were provided, a dry-to-wet ratio of 0.195 was applied.

A stochastic multiplier is recommended to provide greater realism to the model. This multiplier samples along a log-normal distribution that is truncated. This distribution curve is based on similar modeling performed in support of the U.S. Department of Energy's Yucca Mountain Project, which also applied a log-normal distribution for soil-to-plant transfers. [ML090720287] The geometric mean value for this multiplier is 1.0, ensuring that (when applied) the mean is equal to the deterministic value. The standard deviation was calculated using a logarithmic line-fit curve, comparing the ratio of the mean values to the standard deviations from the values reported in IAEA-472. The minimum and maximum values for the probabilistic multiplier were developed based on various ratios between recommended, minimum, and maximum values.

Table 7.3-1: Soil-to-Plant Transfer Coefficients (Unitless)

Element	Value	Element	Value	Element	Value
Ac	6.00E-05	Ge	3.20E-02	Po	7.92E-04
Ag	1.25E-04	H	1.15E+00	Pr	4.80E-03
Al	2.90E-04	Ha	4.80E-04	Pt	8.80E-03
Am	7.74E-05	He	1.00E-20	Pu	2.19E-05
Ar	1.00E-20	Hf	1.93E-04	Ra	7.60E-03
As	2.52E-03	Hg	8.52E-02	Rb	2.05E-01
At	7.00E-02	Ho	3.85E-03	Re	1.13E-01
Au	2.66E-03	I	1.07E-02	Rf	7.20E-04
B	5.60E-01	In	2.21E-04	Rh	1.86E-01
Ba	9.63E-04	Ir	4.49E-03	Rn	1.00E-20
Be	6.29E-04	K	1.36E-01	Ru	6.39E-03
Bi	9.63E-02	Kr	1.00E-20	S	2.89E-01
Bk	2.40E-04	La	8.78E-04	Sb	2.95E-04
Br	2.89E-01	Li	1.80E-03	Sc	3.93E-04
C	1.35E-01	Lr	4.80E-04	Se	1.76E-02
Ca	4.14E+00	Lu	1.20E-03	Si	2.47E-02
Cd	1.74E-01	Md	4.80E-04	Sm	3.85E-03
Ce	2.28E-03	Mg	1.24E-01	Sn	2.12E-03
Cf	6.00E-05	Mn	6.58E-02	Sr	1.37E-01
Cl	3.32E+00	Mo	8.44E-02	Ta	4.82E-03
Cm	1.37E-04	N	7.36E-03	Tb	3.85E-03
Co	2.48E-02	Na	5.78E-03	Tc	1.14E+01
Cr	1.93E-04	Nb	2.18E-03	Te	5.78E-02
Cs	7.03E-03	Nd	3.85E-03	Th	1.65E-04
Cu	5.42E-02	Ne	1.00E-20	Ti	8.20E-04
Dy	3.85E-03	Ni	2.04E-02	Tl	2.21E-04
Er	3.85E-03	No	4.80E-04	Tm	1.20E-03
Es	2.40E-04	Np	4.05E-03	U	2.58E-03
Eu	3.85E-03	O	1.44E-01	V	8.20E-04
F	3.32E-03	Os	6.19E-03	W	5.78E-01
Fe	1.40E-02	P	1.93E-01	Xe	1.00E-20
Fm	4.80E-04	Pa	6.00E-05	Y	3.85E-04
Fr	6.12E-02	Pb	5.26E-03	Yb	1.20E-03
Ga	2.21E-04	Pd	1.21E-02	Zn	1.79E-01
Gd	3.85E-03	Pm	2.46E-02	Zr	7.70E-04

Recommended Values for Probabilistic Multiplier

Distribution	Mean (geom.)	S.D (geom.)	Min	Max
Log-Normal (truncated)	1.0	3.7	0.073	51.4

Notes: Elements in this table that show a value of 1.00E-20 are assumed to have a negligible effect, if any, on dose calculations. However, some modeling practices require a non-zero value such that this very small value is recommended.

7.3.2 Feed-to-Meat Transfer Coefficients

Table 7.3-2 provides a listing of the recommended transfer coefficients for the feed-to-meat biotic accumulation. The equations in Sections 3 through 6 identify this modeling parameter with the following symbol: TC_{MEAT}. The recommended values were developed according to the process shown in Figures 7.3-1 and 7.3-2.

Revision 1 of the HTF PA represents the first time that probabilities were applied to this modeling parameter in the current Liquid Waste PAs. [SRR-CWDA-2010-00128] For simplicity and due to a lack of specific guidance a triangular distribution was used; however, review of the probabilistic results revealed that the triangular distribution was unrealistic and provided very unlikely doses that could be tempered by applying a more realistic distribution curve (see Section 5.6.4.3.4 of the HTF PA). [SRR-CWDA-2010-00128] A literature review found a similar probabilistic modeling parameter had been developed in support of the U.S. Department of Energy's Yucca Mountain Project. [ML090720287] The Yucca Mountain Project report recommends using a log-normal distribution. This distribution was applied to the Liquid Waste PA dose calculator through the use of a multiplier. The geometric mean value for this multiplier is 1.0, ensuring that (when applied) the mean is equal to the deterministic value. The standard deviation is the average of the standard deviations from similar parameters used by the Yucca Mountain Project. The minimum and maximum values for the probabilistic multiplier were developed based on various ratios between recommended, minimum, and maximum values from various sources.

The values presented here were converted from day/kg to yr/kg by dividing the initial values by 365.25 day/yr.

Table 7.3-2: Feed-to-Meat Transfer Coefficients (yr/kg)

Element	Value	Element	Value	Element	Value
Ac	1.10E-06	Ge	1.92E-03	Po	1.37E-05
Ag	8.21E-06	H	1.00E-20	Pr	5.48E-08
Al	4.11E-06	Ha	1.37E-08	Pt	1.10E-05
Am	1.37E-06	He	1.00E-20	Pu	3.01E-09
Ar	1.00E-20	Hf	2.74E-06	Ra	4.65E-06
As	5.48E-06	Hg	6.84E-04	Rb	2.74E-05
At	2.74E-05	Ho	8.21E-07	Re	2.19E-05
Au	1.37E-05	I	1.83E-05	Rf	1.00E-20
B	2.19E-06	In	2.19E-05	Rh	5.48E-06
Ba	3.83E-07	Ir	4.11E-06	Rn	1.00E-20
Be	2.74E-06	K	5.48E-05	Ru	9.03E-06
Bi	1.10E-06	Kr	1.00E-20	S	5.48E-04
Bk	6.84E-08	La	3.56E-07	Sb	3.29E-06
Br	6.84E-05	Li	2.74E-05	Sc	4.11E-05
C	8.49E-05	Lr	5.48E-07	Se	4.11E-05
Ca	3.56E-05	Lu	1.23E-05	Si	1.10E-07
Cd	1.59E-05	Md	1.00E-20	Sm	8.65E-07
Ce	5.48E-08	Mg	5.48E-05	Sn	2.19E-04
Cf	1.10E-07	Mn	1.64E-06	Sr	3.56E-06
Cl	4.65E-05	Mo	2.74E-06	Ta	3.67E-08
Cm	1.10E-07	N	2.05E-04	Tb	5.48E-08
Co	1.18E-06	Na	4.11E-05	Tc	1.73E-05
Cr	2.46E-05	Nb	7.12E-10	Te	1.92E-05
Cs	6.02E-05	Nd	5.48E-08	Th	6.30E-07
Cu	2.46E-05	Ne	1.00E-20	Ti	8.21E-05
Dy	5.48E-08	Ni	1.37E-05	Tl	1.10E-04
Er	5.48E-08	No	5.48E-07	Tm	1.23E-05
Es	6.84E-08	Np	2.74E-06	U	1.07E-06
Eu	5.48E-08	O	1.00E-20	V	6.84E-06
F	4.11E-04	Os	1.10E-03	W	1.10E-04
Fe	3.83E-05	P	1.51E-04	Xe	1.00E-20
Fm	5.48E-07	Pa	1.22E-06	Y	2.74E-06
Fr	6.84E-06	Pb	1.92E-06	Yb	1.10E-05
Ga	1.37E-06	Pd	1.10E-05	Zn	4.38E-04
Gd	5.48E-08	Pm	5.48E-08	Zr	3.29E-09

Recommended Values for Probabilistic Multiplier

Distribution	Mean (geom.)	S.D (geom.)	Min	Max
Log-Normal (truncated)	1.0	5.8	0.15	46

Notes: Elements in this table that show a value of 1.00E-20 are assumed to have a negligible effect, if any, on dose calculations. However, some modeling practices require a non-zero value such that this very small value is recommended.

7.3.3 Feed-to-Milk Transfer Coefficients

Table 7.3-3 provides a listing of the recommended transfer coefficients for the feed-to-milk biotic accumulation. The equations in Sections 3 through 6 identify this modeling parameter with the following symbol: TC_{MILK} . The recommended values were developed according to the process shown in Figures 7.3-1 and 7.3-2.

As with the transfer coefficient for feed-to-meat, the previously used triangular distribution for this parameter was unrealistic. A literature review found a similar probabilistic modeling parameter had been developed in support of the U.S. Department of Energy's Yucca Mountain Project. [ML090720287] The Yucca Mountain Project report indicates using a log-normal distribution. This new distribution was applied to the dose calculator as a multiplier. The geometric mean value for this multiplier is 1.0, ensuring that (when applied) the mean is equal to the deterministic value. The standard deviation is the average of the standard deviations from similar parameters used by the Yucca Mountain Project. The minimum and maximum values for the probabilistic multiplier were developed based on various ratios between recommended, minimum, and maximum values from various sources.

The values presented here were converted from day/L to yr/L by dividing the initial values by 365.25 day/yr.

7.3.4 Feed-to-Poultry Transfer Coefficients

Table 7.3-4 provides a listing of the recommended transfer coefficients for the feed-to-poultry biotic accumulation. The equations in Sections 3 through 6 identify this modeling parameter with the following symbol: $TC_{POULTRY}$. The recommended values were developed according to the process shown in Figures 7.3-1 and 7.3-2. Poultry is not expected to be a significant a dose contributor, relative to other intakes; therefore, for simplicity, no stochastic probability is assumed for this parameter.

The values presented here were converted from day/kg to yr/kg by dividing the initial values by 365.25 day/yr.

Table 7.3-3: Feed-to-Milk Transfer Coefficients (yr/L)

Element	Value	Element	Value	Element	Value
Ac	5.48E-08	Ge	1.97E-04	Po	5.75E-07
Ag	4.33E-06	H	4.11E-05	Pr	8.21E-08
Al	5.64E-07	Ha	1.37E-08	Pt	1.41E-05
Am	1.15E-09	He	1.00E-20	Pu	2.74E-08
Ar	1.00E-20	Hf	1.51E-09	Ra	1.04E-06
As	1.64E-07	Hg	1.29E-06	Rb	3.29E-05
At	2.82E-05	Ho	8.21E-08	Re	4.11E-06
Au	1.51E-08	I	1.48E-05	Rf	5.48E-08
B	4.23E-06	In	5.48E-07	Rh	2.74E-05
Ba	4.38E-07	Ir	5.48E-09	Rn	1.00E-20
Be	2.27E-09	K	1.97E-05	Ru	2.57E-08
Bi	1.37E-06	Kr	1.00E-20	S	2.16E-05
Bk	5.48E-09	La	5.48E-08	Sb	1.04E-07
Br	5.48E-05	Li	5.64E-05	Sc	1.37E-08
C	3.29E-05	Lr	1.37E-08	Se	1.10E-05
Ca	2.74E-05	Lu	5.64E-08	Si	5.48E-08
Cd	5.20E-07	Md	1.37E-08	Sm	8.21E-08
Ce	5.48E-08	Mg	1.07E-05	Sn	2.74E-06
Cf	4.11E-09	Mn	1.12E-07	Sr	3.56E-06
Cl	4.65E-05	Mo	3.01E-06	Ta	1.12E-09
Cm	5.48E-08	N	6.84E-05	Tb	8.21E-08
Co	3.01E-07	Na	3.56E-05	Tc	5.12E-06
Cr	1.18E-06	Nb	1.12E-09	Te	9.31E-07
Cs	1.26E-05	Nd	8.21E-08	Th	1.37E-08
Cu	5.48E-06	Ne	1.00E-20	Ti	2.82E-05
Dy	8.21E-08	Ni	2.60E-06	Tl	5.48E-06
Er	8.21E-08	No	1.37E-08	Tm	5.64E-08
Es	5.48E-09	Np	1.37E-08	U	4.93E-06
Eu	8.21E-08	O	1.00E-20	V	5.64E-08
F	2.74E-06	Os	1.37E-05	W	5.20E-07
Fe	9.58E-08	P	5.48E-05	Xe	1.00E-20
Fm	1.00E-20	Pa	1.37E-08	Y	5.48E-08
Fr	5.64E-05	Pb	5.20E-07	Yb	5.64E-08
Ga	1.37E-07	Pd	2.74E-05	Zn	7.39E-06
Gd	8.21E-08	Pm	8.21E-08	Zr	9.86E-09

Recommended Values for Probabilistic Multiplier

Distribution	Mean (geom.)	S.D (geom.)	Min	Max
Log-Normal (truncated)	1.0	3.0	0.3	12

Notes: Elements in this table that show a value of 1.00E-20 are assumed to have a negligible effect, if any, on dose calculations. However, some modeling practices require a non-zero value such that this very small value is recommended.

Table 7.3-4: Feed-to-Poultry Transfer Coefficients (yr/kg)

Element	Value	Element	Value	Element	Value
Ac	1.64E-05	Ge	1.00E-20	Po	6.57E-03
Ag	5.48E-03	H	1.00E-20	Pr	5.48E-06
Al	1.00E-20	Ha	1.00E-20	Pt	1.00E-20
Am	1.64E-05	He	1.00E-20	Pu	8.21E-06
Ar	1.00E-20	Hf	1.64E-07	Ra	8.21E-05
As	2.27E-03	Hg	8.21E-05	Rb	5.48E-03
At	1.00E-20	Ho	5.48E-06	Re	1.10E-04
Au	2.74E-03	I	2.38E-05	Rf	1.00E-20
B	1.00E-20	In	2.19E-03	Rh	5.48E-03
Ba	5.20E-05	Ir	5.48E-03	Rn	1.00E-20
Be	1.10E-03	K	1.10E-03	Ru	1.92E-05
Bi	2.68E-04	Kr	1.00E-20	S	6.30E-03
Bk	1.00E-20	La	2.74E-04	Sb	1.64E-05
Br	1.10E-05	Li	1.00E-20	Sc	1.10E-05
C	1.00E-20	Lr	1.00E-20	Se	2.66E-02
Ca	1.20E-04	Lu	1.00E-20	Si	2.19E-03
Cd	4.65E-03	Md	1.00E-20	Sm	5.48E-06
Ce	5.48E-06	Mg	8.21E-05	Sn	2.19E-03
Cf	1.64E-05	Mn	5.20E-06	Sr	5.48E-05
Cl	8.21E-05	Mo	4.93E-04	Ta	8.21E-07
Cm	1.64E-05	N	2.68E-04	Tb	5.48E-06
Co	2.66E-03	Na	1.92E-02	Tc	8.21E-05
Cr	5.48E-04	Nb	8.21E-07	Te	1.64E-03
Cs	7.39E-03	Nd	5.48E-06	Th	1.64E-05
Cu	1.37E-03	Ne	1.00E-20	Ti	1.00E-20
Dy	5.48E-06	Ni	2.74E-06	Tl	2.19E-03
Er	5.48E-06	No	1.00E-20	Tm	1.00E-20
Es	1.00E-20	Np	1.64E-05	U	2.05E-03
Eu	5.48E-06	O	1.00E-20	V	1.00E-20
F	3.83E-05	Os	2.30E-04	W	5.48E-04
Fe	2.74E-03	P	5.20E-04	Xe	1.00E-20
Fm	1.00E-20	Pa	1.64E-05	Y	2.74E-05
Fr	1.00E-20	Pb	2.19E-03	Yb	1.00E-20
Ga	2.19E-03	Pd	8.21E-07	Zn	1.29E-03
Gd	5.48E-06	Pm	5.48E-06	Zr	1.64E-07

Notes: Elements in this table that show a value of 1.00E-20 are assumed to have a negligible effect, if any, on dose calculations. However, some modeling practices require a non-zero value such that this very small value is recommended.

7.3.5 Feed-to-Egg Transfer Coefficients

Table 7.3-5 provides a listing of the recommended transfer coefficients for the feed-to-egg biotic accumulation. The equations in Sections 3 through 6 identify this modeling parameter with the following symbol: TC_{EGG}. The recommended values were developed according to the process shown in Figures 7.3-1 and 7.3-2. Eggs are not expected to be a significant a dose contributor, relative to other intakes; therefore, for simplicity, no stochastic probability is assumed for this parameter.

The values presented here were converted from day/kg to yr/kg by dividing the initial values by 365.25 day/yr.

Table 7.3-5: Feed-to-Egg Transfer Coefficients (yr/kg)

Element	Value	Element	Value	Element	Value
Ac	1.10E-05	Ge	1.00E-20	Po	8.49E-03
Ag	1.37E-03	H	1.00E-20	Pr	1.10E-07
Al	1.00E-20	Ha	1.00E-20	Pt	1.00E-20
Am	8.21E-06	He	1.00E-20	Pu	3.29E-06
Ar	1.00E-20	Hf	5.48E-07	Ra	8.49E-04
As	7.12E-04	Hg	1.37E-03	Rb	8.21E-03
At	1.00E-20	Ho	1.10E-07	Re	1.15E-03
Au	1.37E-03	I	6.57E-03	Rf	1.00E-20
B	1.00E-20	In	2.74E-03	Rh	2.74E-04
Ba	2.38E-03	Ir	2.74E-04	Rn	1.00E-20
Be	5.48E-05	K	2.74E-03	Ru	1.10E-05
Bi	7.12E-04	Kr	1.00E-20	S	1.92E-02
Bk	1.00E-20	La	2.46E-05	Sb	1.92E-04
Br	4.38E-03	Li	1.00E-20	Sc	1.15E-05
C	1.00E-20	Lr	1.00E-20	Se	4.38E-02
Ca	1.20E-03	Lu	1.00E-20	Si	2.74E-03
Cd	2.74E-04	Md	1.00E-20	Sm	1.10E-07
Ce	8.49E-06	Mg	5.48E-03	Sn	2.74E-03
Cf	1.10E-05	Mn	1.15E-04	Sr	9.58E-04
Cl	7.39E-03	Mo	1.75E-03	Ta	2.74E-06
Cm	1.10E-05	N	7.12E-04	Tb	1.10E-07
Co	9.03E-05	Na	1.10E-02	Tc	8.21E-03
Cr	2.46E-03	Nb	2.74E-06	Te	1.40E-02
Cs	1.10E-03	Nd	1.10E-07	Th	1.10E-05
Cu	1.37E-03	Ne	1.00E-20	Ti	1.00E-20
Dy	1.10E-07	Ni	2.74E-04	Tl	2.74E-03
Er	1.10E-07	No	1.00E-20	Tm	1.00E-20
Es	1.00E-20	Np	1.10E-05	U	3.01E-03
Eu	1.10E-07	O	1.00E-20	V	1.00E-20
F	7.39E-03	Os	1.94E-04	W	2.46E-03
Fe	4.93E-03	P	1.75E-03	Xe	1.00E-20
Fm	1.00E-20	Pa	1.10E-05	Y	5.48E-06
Fr	1.00E-20	Pb	2.74E-03	Yb	1.00E-20
Ga	2.74E-03	Pd	1.10E-05	Zn	3.83E-03
Gd	1.10E-07	Pm	1.10E-07	Zr	5.48E-07

Notes: Elements in this table that show a value of 1.00E-20 are assumed to have a negligible effect, if any, on dose calculations. However, some modeling practices require a non-zero value such that this very small value is recommended.

7.3.6 Water-to-Fish Transfer Coefficients

Table 7.3-6 provides a listing of the recommended transfer coefficients for the water-to-fish biotic accumulation. The equations in Sections 3 through 6 identify this modeling parameter with the following symbol: TC_{FISH}. The recommended values were developed according to the process shown in Figures 7.3-1 and 7.3-2.

As with the transfer coefficient for feed-to-meat, the previously used triangular distribution for this parameter was unrealistic. A literature review found a similar probabilistic modeling parameter had been developed in support of the U.S. Department of Energy's Yucca Mountain Project. [ML090720287] The Yucca Mountain Project report indicates using a log-normal distribution. This new distribution was applied to the dose calculator as a multiplier. The geometric mean value for this multiplier is 1.0, ensuring that (when applied) the mean is equal to the deterministic value. The standard deviation is the average of the standard deviations from similar parameters used by the Yucca Mountain Project. The minimum and maximum values for the probabilistic multiplier were developed based on various ratios between recommended, minimum, and maximum values from various sources.

Table 7.3-6: Water-to-Fish Transfer Coefficients (L/kg)

Element	Value	Element	Value	Element	Value
Ac	2.50E+01	Ge	4.00E+03	Po	3.60E+01
Ag	1.10E+02	H	1.00E+00	Pr	3.00E+01
Al	5.10E+01	Ha	1.00E-20	Pt	3.50E+01
Am	2.40E+02	He	1.00E+00	Pu	3.00E+01
Ar	1.00E-20	Hf	1.10E+03	Ra	4.00E+00
As	3.30E+02	Hg	6.10E+03	Rb	4.90E+03
At	1.50E+01	Ho	3.00E+01	Re	1.20E+02
Au	2.40E+02	I	3.00E+01	Rf	1.00E-20
B	1.00E-20	In	1.00E+04	Rh	1.00E+01
Ba	1.20E+00	Ir	1.00E+01	Rn	7.55E-10
Be	1.00E+02	K	3.20E+03	Ru	5.50E+01
Bi	1.50E+01	Kr	1.00E-20	S	8.00E+02
Bk	2.50E+01	La	3.70E+01	Sb	3.70E+01
Br	9.10E+01	Li	1.00E-20	Sc	1.90E+02
C	3.00E+00	Lr	1.00E-20	Se	6.00E+03
Ca	1.20E+01	Lu	2.50E+01	Si	2.00E+01
Cd	2.00E+02	Md	1.00E-20	Sm	3.00E+01
Ce	2.50E+01	Mg	3.70E+01	Sn	3.00E+03
Cf	2.50E+01	Mn	2.40E+02	Sr	2.90E+00
Cl	4.70E+01	Mo	1.90E+00	Ta	3.00E+02
Cm	3.00E+01	N	2.00E+05	Tb	4.10E+02
Co	7.60E+01	Na	7.60E+01	Tc	2.00E+01
Cr	4.00E+01	Nb	3.00E+02	Te	1.50E+02
Cs	2.50E+03	Nd	3.00E+01	Th	6.00E+00
Cu	2.30E+02	Ne	1.00E-20	Ti	1.90E+02
Dy	6.50E+02	Ni	2.10E+01	Tl	9.00E+02
Er	3.00E+01	No	1.00E-20	Tm	1.00E-20
Es	2.50E+01	Np	2.10E+01	U	9.60E-01
Eu	1.30E+02	O	1.00E+00	V	9.70E+01
F	1.00E+01	Os	1.00E+03	W	1.00E+01
Fe	1.70E+02	P	1.40E+05	Xe	1.00E-20
Fm	1.00E-20	Pa	1.00E+01	Y	4.00E+01
Fr	3.00E+01	Pb	2.50E+01	Yb	1.00E-20
Ga	4.00E+02	Pd	1.00E+01	Zn	3.40E+03
Gd	3.00E+01	Pm	3.00E+01	Zr	2.20E+01

Recommended Values for Probabilistic Multiplier

Distribution	Mean (geom.)	S.D (geom.)	Min	Max
Log-Normal (truncated)	1.0	2.7	0.29	25

Notes: Elements in this table that show a value of 1.00E-20 are assumed to have a negligible effect, if any, on dose calculations. However, some modeling practices require a non-zero value such that this very small value is recommended.

7.4 Exposure and Inhalation Parameters

The amount of exposure and inhalation that a human receptor is subjected to is influenced by human behavior and environmental conditions. For example, in the acute IHI scenario the human receptor is exposed to drill cuttings because they are assumed to be the driller who is drilling into the contaminated source. A number of parameters within the equations from Sections 3 through 6 require definitions. Recommendations for these parameters are provided in Table 7.4-1.

Table 7.4-1: Exposure and Inhalation Parameters

Parameter	Symbol in Equations	Unit	Value [a]	Probabilistic Multiplier				
				Distribution	Mean/Mode	SD	Min	Max
fraction of time spent in a contaminated garden	$F_{t,g}$	none	2.7E-02 [b]	Triangular	1.0	N/A	0.5	2.0
fraction of time spent showering or bathing	$F_{t,SHOWER}$	none	1.2E-02 [b]	Log-Normal	0.85	0.65	0.25	1.52
geometry factor [c] for showering or bathing	GF_{SHOWER}	none	1 [d]	N/A	N/A	N/A	N/A	N/A
fraction of time spent swimming	$F_{t,SWIM}$	none	1.7E-03 [b]	Triangular	1.0	N/A	0	3.3
geometry factor [c] for swimming	GF_{SWIM}	none	1 [d]	N/A	N/A	N/A	N/A	N/A
fraction of time spent boating	$F_{t,BOAT}$	none	2.5E-03 [e]	N/A	N/A	N/A	N/A	N/A
geometry factor [c] for boating	GF_{BOAT}	none	0.5 [d]	N/A	N/A	N/A	N/A	N/A
fraction of time spent drilling into contaminated source	$F_{t,d}$	none	2.3E-03 [d]	Triangular	1.0	N/A	0.1	2.0
airborne release fraction	ARF	none	1.0E-4 [d,f]	Uniform	N/A	N/A	0.04	2.0
moisture content of ambient air	MC_{air}	kg/m^3	1.0E-02 [d]	N/A	N/A	N/A	N/A	N/A
moisture content of shower air	MC_{SHOWER}	kg/m^3	4.1E-02 [g]	N/A	N/A	N/A	N/A	N/A
mass loading of soil in the air	L_{soil}	kg/m^3	1.0E-7	Triangular	1.0	N/A	0.1	3.0

a This is the recommended value, for use in deterministic modeling.
b See discussion in Appendix B.
c The geometry factor is the fraction of the human body that is assumed to be exposed to contaminants during a specific activity.
d Conservative assumption
e From SRNL-STI-2010-00447, Rev 0, Table 10
f From DOE-HDBK-3010-94, Table 3-6
g From HNF-SD-WM-TI-707, Table A12
h From WSRC-STI-2007-00004, Rev. 4, Table 3-2
SD = standard deviation
N/A = Not Applicable

Note that doses due to boating exposures are expected to be minor, relative to the other pathways; therefore no stochastic probability is assumed for these parameters.

To account for the quantity of contaminants released into the air and available for inhalation, the Airborne Release Fraction (ARF) is included in some of the inhalation pathway calculations. The ARF value was selected based on information in Section 3.2.3.1 of *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities, Volume 1 - Analysis of Experimental Data*. [DOE-HDBK-3010-94] This reference report indicates that aqueous solutions subjected to free-fall spills have a median ARF of 4E-05 and a bounding value of 2E-04. For simplicity, the ARF is conservatively assumed to be 1E-04 (i.e., half the conservative bounding value and two and a half times greater than the median).

Appendix B provides additional discussion of the development of select parameters.

7.5 Physical Parameters

Physical parameters are used to define various environmental factors that influence the movement and accumulation of contaminants prior to uptake by the human receptor. Physical parameters for dose calculations used in Liquid Waste PAs can be organized into three groups: (1) soil parameters, (2) crop and gardening parameters, (3) drilling parameters. Recommended values for each of these sets of physical parameters are defined below.

7.5.1 Soil Buildup Parameters

Table 7.5-1 shows recommended values for physical soil parameters.

Table 7.5-1: Soil Parameters

Parameter	Symbol in Equations	Unit	Value [a]	Probabilistic Multiplier				
				Distribution	Mean / Mode	SD	Min	Max
buildup time of radionuclides in soil	t_b	yr	25[b]	N/A	N/A	N/A	N/A	N/A
surface (or areal) density of soil	ρ_{ss}	kg/m^2	240	Normal	1.0	0.07	0.83	1.15
dry bulk density of soil	ρ_S	kg/m^3	1650 [c]					
precipitation rate	PR	m/yr	1.25 [d]	N/A	N/A	N/A	N/A	N/A
evapotranspiration rate[d]	ER	m/yr	0.79 [d]	N/A	N/A	N/A	N/A	N/A
irrigation rate	IR	m/yr	1.32[e]	Triangular	1.0	N/A	0.5	1.5
radiological decay constant of radionuclide *i*	λ_i	1/yr	Varies [f]	N/A	N/A	N/A	N/A	N/A
weathering decay constant	λ_w	1/yr	18.1	Triangular	1.0	N/A	0.6	1.0
soil moisture content	MC_{soil}	none	0.2086[g]	N/A	N/A	N/A	N/A	N/A

[WSRC-STI-2007-00004, Rev. 4, Table 3-2 except as noted]; N/A = Not applicable

a This is the recommended value, for use in deterministic modeling.

b From SRNL-STI-2010-00447, Rev 0, Table 1

c From WSRC-STI-2006-00198, Rev. 0, Table 5-9 (assumes Upper Vadose Zone soil). The normal distribution was based on the recommended distribution of the surface soil density. Also note that because dry bulk soil density and surface soil density are closely related physical parameters, the two variables should be modeled with a perfect (1-to-1) correlation.

d From WSRC-STI-2007-00184, Rev 2

e Converted from $L/d/m^2$. As described in the reference document, this is based on an assumed irrigation rate of 1 inch per week.

f radiological decay constant of radionuclide *i* = ln(2)/(half-life of radionuclide *i*)

g From SRR-CWDA-2010-00128, Rev. 1, Table 4.6-8

7.5.2 Crop and Gardening Parameters

Table 7.5-2 shows recommended values for physical parameters related to crops and gardening.

Table 7.5-2: Crop and Gardening Parameters

Parameter	Symbol in Equations	Unit	Value [a]	Probabilistic Multiplier				
				Distribution	Mean / Mode	SD	Min	Max
fraction of material deposited on leaves that is retained	F_r	unitless	0.25 [b]	Triangular	1.0	N/A	0.8	1.0
fraction of material remaining on leaves after washing	F_{wash}	unitless	1 [c]	N/A	N/A	N/A	N/A	N/A
time in which crops and gardens are irrigated	t_{irr}	yr	1.92E-01	Normal	1.0	0.1	0.85	1.28
fraction of year in which crops are irrigated	F_{irr}	unitless	t_{irr} per year [d]	N/A	N/A	N/A	N/A	N/A
crop and garden yield (agricultural productivity)	Y_g	kg/m^2	2.2 [e]	Log-Normal	1.0	0.23	0.1	1.8
depth of crop garden tilling	d_{till}	m	0.15	Triangular	1.0	N/A	1.0	4.1
fraction of produce that is leafy	F_{leaf}	unitless	0.2 [f]	N/A	N/A	N/A	N/A	N/A
Area of garden for family of four	A_{garden}	m^2	100	Triangular	1.0	N/A	1.0	10.0

[WSRC-STI-2007-00004, Rev. 4, Table 3-2 except as noted]; N/A = Not applicable

a This is the recommended value, for use in deterministic modeling.

b Consistent with the footnote in Table 3-2 of the reference document (WSRC-STI-2007-00004, Rev. 4), the retention fraction for Iodine should by multiplied by four (i.e., 0.25 × 4 = 1.0).

c Conservative assumption

d $F_{irr} = t_{irr}$ / 1 year

e From SRNL-STI-2010-00447, Rev 0, Section 3.1.1.1

f From SRNL-STI-2010-00447, Rev 0, Section 3.1.2

7.5.3 Drilling Parameters

Table 7.5-3 shows recommended values for physical parameters related drilling a well.

Table 7.5-3: Drilling Parameters

Parameter	Symbol in Equations	Unit	Value [a]	Probabilistic Multiplier				
				Distribution	Mean / Mode	SD	Min	Max
well diameter	$well_{diam}$	m	0.203 [b]	N/A	N/A	N/A	N/A	N/A
transfer line area per length	N/A [c]	m^2/m	0.245 [d]	N/A	N/A	N/A	N/A	N/A
water density	ρ_{H2O}	kg/L	1 [e]	N/A	N/A	N/A	N/A	N/A
well depth	$well_{dep}$	m	30.5 [b,f]	Log-Normal	1.85	0.75	0.3	9.9

N/A = Not applicable

a This is the recommended value, for use in deterministic modeling.

b From SRR-CWDA-2010-00054.

c This value is not used in the equations from Section 3 through 6; however it is provided here as a parameter that is used in the standard approach for calculating drill cutting inventories in the IHI scenarios.

d From SRR-CWDA-2010-00128, Rev. 1, Table 4.6-8. Converted from 0.803 ft^2/ft.

e Assumed value.

f Because the recommended deterministic value is different from the recommended mean value, additional discussion of the well depth parameter is provided in Appendix B.

7.6 Local Fraction (Productivity) Parameters

The following describes the local fraction (or local productivity) parameters. These parameters are used to define the fraction of food intake that is home-produced, as opposed to coming from other sources. For example, although the MOP is assumed to have a garden, current practices indicate that only a fraction of produce consumed comes directly from an individual garden. As such, only a fraction of the consumed produce would be contaminated.

Table 7.6-1 provides a summary of the recommended values. All of these parameters directly from the EPA's *Exposure Factors Handbook* and are consistent with the definition of the critical group given in Section 1.1. [EPA-600-R-090-052F, Table 13-68] For sampling, a triangular distribution is assumed with a mode equal to the recommended fraction, the maximum is assumed to be double the recommended value, and the minimum is assume to be half the recommended value.

The EPA's *Exposure Factors Handbook* provided comprehensive water ingestion data. [EPA-600-R-090-052F] The local fraction is already be incorporated within the recommended value developed for Table 7.2-1.

Table 7.6-1: Recommended Fractional Values for Local Productivity

Fraction of Foodstuff Produced Locally		Mode	Min	Max
Symbol in Equations	**Parameter Description**			
$F_{local,H2O}$ [a]	The fraction of consumed water that comes from the contaminated water source	N/A	N/A	N/A
$F_{local,PLANT}$ $F_{IHI,local,PLANT}$	The fraction of total produce grown at home.	0.068	0.034	0.136
$F_{local,MEAT}$ $F_{IHI,local,MEAT}$	The fraction of total terrestrial livestock meat produced at home.	0.024	0.012	0.048
$F_{local,MILK}$ $F_{IHI,local,MILK}$	The fraction of total milk produced at home.	0.012	0.006	0.024
$F_{local,POULTRY}$ $F_{IHI,local,POULTRY}$	The fraction of total poultry produced at home.	0.011	0.0055	0.022
$F_{local,EGG}$ $F_{IHI,local,EGG}$	The fraction of total eggs produced at home.	0.014	0.007	0.028
$F_{local,FISH}$	The fraction of households that fish.	0.094	0.047	0.188

[EPA-600-R-090-052F]

a The local fraction for water consumption has already been incorporated into the uptake parameter (U_{H2O}) shown in Table 7.2-1 and discussed in Appendix B.

7.7 Distribution Coefficients (K_ds)

The soil underlying the FTF, HTF, and SDF have a propensity to slow the transport of certain radionuclides through the environment, thus retarding their arrival to a potential receptor. The ability of the cementitious materials or the soils to sorb the different radionuclides is represented using K_ds. The ability of the material to sorb the radionuclide is dependent on the chemical condition of the environment. Table 7.7-1 shows the deterministic K_d values for the sandy soils, as used in the dose calculations for soil buildup. The K_d values are element dependent. A discussion of the sampling approach follows this table.

Table 7.7-1: Recommended Sandy Soil K_d Values

Element	K_d (L/kg)	Ref.	Element	K_d (L/kg)	Ref.
Ac	1100	a	Mn	15	a
Ag	10	b	Mo	1000	a
Al	1300	a	Na	5	a
Am	1100	a	Nb	160	d
As	100	a	Ni	7	a
At	0.3	a	Np	3	a
Ba	15	c	Pa	3	a
Bi	1100	a	Pb	2000	a
Bk	1100	a	Pd	7	a
C	10	a	Po	2000	a
Ca	5	a	Pt	7	a
Cd	15	a	Pu	650	e
Ce	1100	a	Ra	25	c
Cf	1100	a	Rb	10	a
Cl	1	b	Re	0.6	a
Cm	1100	a	Sb	2500	a
Co	40	a	Se	1000	a
Cr	1000	b	Sm	1100	a
Cs	10	a	Sn	2000	a
Cu	50	a	Sr	5	c
Eu	1100	a	Tc	0.6	a
Fe	200	a	Te	1000	a
Fr	10	a	Th	900	a
Gd	1100	a	Tl	25	f
Hg	800	a	U	300	f
I	1	g	Y	1100	a
K	5	a	Zn	15	a
Lu	1100	a	Zr	900	a

a From SRNL-STI-2009-00473, Table 16
b From SRNL-STI-2010-00493, Table 9
c From SRNL-STI-2011-00011, Table 2-2
d From ML073510127, Section 2.4.5
e From SRNL-STI-2011-00672, Section 5
f From SRNL-STI-2010-00493, Table 8
g From SRNL-STI-2012-00518, Table 9
Note: Any elements not listed in this table are assumed to have a minimal impact on the soil buildup calculation (Equation 3.1-3c) with respect to dose. Therefore, a conservative value of 1.0e-20 L/kg may be assumed when modeling elements that are not listed. 1 mL/g = 1 L/kg.

For probabilistic modeling, a lognormal distribution is recommended with geometric mean and standard deviation. [SRNL-STI-2009-00150] Table 7.7-2 provides the recommended distributions for use in dose modeling. These distributions are constructed using the recommended deterministic values.

Table 7.7-2: K_d Variability in Sandy Soil

IF Condition	THEN			
	GM	GSD	Min	Max
$K_d < 2.7$ L/kg	K_d	1.001	$K_d \times 0.25$	$K_d \times 1.75$
$K_d \geq 2.7$ L/kg	K_d	$K_d \times 0.375$	$K_d \times 0.25$	$K_d \times 1.75$

K_d = the recommended Kd value from Table 7.7-1
GM = geometric mean of the lognormal distribution
GSD = geometric standard deviation of the lognormal distribution

Here, the geometric mean (GM) is equal to the recommended deterministic value. Elements with a deterministic K_d less than 2.7 L/kg will have a geometric standard deviation (GSD) equal to 1.001, but for elements with a deterministic K_d greater than or equal to 2.7 L/kg, the GSD is calculated as the product of 0.375 and the deterministic value. While a GSD of 1.001 results in a small distribution around the GM, this is only for elements that already have a low deterministic value and thus have low retardation which for soil include technetium and iodine. Of particular interest is the technetium, which has a deterministic value in sandy soil of 0.6 L/kg and a small distribution around this value. The dispersion of technetium K_d values was evaluated in SRNS-STI-2008-00286 and the mean was 3.4 L/kg with a 95th percentile range of 2.4 to 4.4 L/kg. Therefore, the recommended deterministic value is already conservative based on the site-specific data such that it would be inappropriate to allow the distribution to range lower.

8.0 CONCLUSION

The calculations and methods described in Sections 3 through 6 expand on the approaches described in the current Liquid Waste PAs (see Table 1.0-1) and provide greater transparency with respect to the respective calculations. The parameter values provided in Section 7 represent the most current or the most applicable data available. As such, greater confidence can be achieved through the application of this information.

Appendix C uses concentration data from the current Liquid Waste PAs and applies this revised dose calculation. The appendix shows that dose results are generally lower, overall, indicating that doses reported in the current Liquid Waste PAs should be considered conservative. As such, the information in this report should not significantly impact any previous PA-related decisions.

9.0 REFERENCES

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APPENDIX A
ASSUMPTIONS

APPENDIX A. ASSUMPTIONS

The dose calculation approach described herein is driven by a number of general assumptions. These assumptions ensure that the methodology and parameter development follow consistent approaches and can be reproduced. These assumptions are provided in Table A-1. Many of these assumptions are directly related to the definition of exposure scenarios and the human receptors. Others provide guidance to support a consistent approach to parameter development.

Table A-1: Description of Assumptions Supporting the Dose Calculation Methodology

Assumption	Description	Justification or Explanation
A1	Human receptors (both MOP and IHI) are assumed to be age- and gender- weighted (i.e., a typical or reference person) with habits represented by the median habits of the population.	Based on the applicability of the dose coefficients derived in the within the *DOE Standard: Derived Concentration Technical Standard*. [DOE-STD-1196-2011]
A2	It is assumed that the MOP and IHI receptors perform gardening and farming activities in a manner that reflects the median behavior of the total population.	This assumption is based on the definition of the critical group of human receptors (Section 1.1).
A3	It is assumed that a contaminated community well is the primary drinking source of the receptor. All other sources of drinking water are assumed to be free of contaminants. The receptor also bathes in and gardens/farms with contaminated water.	This assumption is based on defined modeling scenarios (Section 1.2) and the definition of the critical group of human receptors (Section 1.1).
A4	It is assumed that all local swimming and boating is only performed in stream water with the highest concentration of contaminants.	This assumption is based on defined modeling scenarios (Section 1.2) and the definition of the critical group of human receptors (Section 1.1).
A5	It is assumed that all local terrestrial livestock and local poultry drink contaminated water and consume fodder irrigated with contaminated water.	This assumption is based on defined modeling scenarios (Section 1.2) and the definition of the critical group of human receptors (Section 1.1).
A6	For tank farms, the IHI scenarios assume a transfer line intrusion will occur 100 years after facility closure. For SDF, the IHI scenarios assume no intrusion will occur.	This assumption is based on defined modeling scenarios (Section 1.2).
A7	The acute IHI scenario assumes that (1) a drilled well is installed that penetrates the closed liquid waste facility (i.e., into the contaminated groundwater for the saltstone disposal facility, and into a transfer line and the contaminated groundwater for the tank farms), and (2) the IHI receptor, in turn, is exposed to ingestion and inhalation of dust and material from drill cuttings, and direct exposure through handling the contaminated drill cuttings.	This assumption is based on the definition of the critical group of human receptors (Section 1.1).
A8	It is assumed that the receptor ingests food at the moment that it is prepared (e.g., harvested or slaughtered), rather than modeling a lag period of a few days between preparation and consumption.	Given the relatively long durations considered for Liquid Waste PA modeling, this conservative assumption is expected to have a negligible impact on results.

Assumption	Description	Justification or Explanation
A9	For data interpretation required to develop parameter values, the human population ratio of males to females shall be 0.48-to-0.52.	This ratio was derived from data Table 4 of *Site Specific Reference Person Parameters and Derived Concentration Standards for the Savannah River Site*. [SRNL-STI-2013-00115] Specifically, the data for the "Adult" age group for the South Carolina and Georgia counties were used.
A10	For development of human uptake parameters, the receptor is assumed to be representative of typical (i.e., "per capita") behaviors.	This assumption is based on the definition of the critical group of human receptors (Section 1.1).
A11	For development of parameter values that are based on survey data from the EPA's 2011 *Exposure Factors Handbook*, all applicable surveys shall be considered, regardless of when the surveys were taken.	Given the extensive time periods modeled in Liquid Waste PAs this approach is appropriate. Using multiple surveys provides greater depth in understanding human behavior over time.
A12	For development of parameter distributions that are based on survey data from the EPA's 2011 *Exposure Factors Handbook*, only data between the 10^{th} and 90^{th} percentiles shall be used.	Many of the surveys were based on a single day or two days of data, such that extrapolating the values over an entire year can result in extreme ranges. By bounding the data with the 10th and 90th percentiles of the surveyed data, the probability sampling will provide results that are more realistic and representative.
A13	For parameters in which a recommended deterministic value has been determined but for which no distribution data is available, a related (analogous) dataset may be used by assuming a linear relationship and scaling the distribution of data.	This assumption allows a reasonable sampling distribution to be developed and applied.
A14	For parameters with limited available data (i.e., only minimum, maximum, and expected values), a triangular distribution shall be assumed.	This assumption allows a reasonable sampling distribution to be developed and applied.
A15	The density of water is assumed to be 1.00 kg/L and the density of milk is assumed to be 1.03 kg/L.	This assumption is needed for a number of PA modeling and dose calculations. The water value is a generally accepted analogue. The milk value is based on Section 2.2 of ORNL-5786.
A16	DCFs from short-lived progeny are assumed to be in secular equilibrium with the parent radionuclides.	This is a modeling simplification to reduce the number of modeled species by combining short-lived radionuclides with their longer-lived parents.
A17	For deterministic modeling, wells are assumed to be drilled to a depth of 100 feet.	This is a conservative modeling simplification.
A18	It is assumed that soil contaminants (both from irrigation and drill cuttings, as applicable) are uniformly distributed at a depth of 0.15 m.	This is a modeling simplification.
A19	For determining the buildup of radionuclides in surface soil (see Equation 3.1-3b), it is assumed that the effects of radionuclide ingrowth are balanced by the effects of weathering, such that both may be ignored.	This is a modeling simplification.
A20	An irrigation rate of 1 inch per week shall be assumed.	This is a modeling simplification.

Assumption	Description	Justification or Explanation
A21	It is assumed that runoff from precipitation does not influence contaminant concentrations in surface soil.	This is a modeling simplification.
A22	For parameters related to dose pathways that are expected to have a minor or negligible impact on dose (e.g., poultry ingestion, egg ingestion, boating exposure, etc.), a single conservative value may be assumed for probabilistic modeling in lieu of developing a sampling distribution.	This is a modeling simplification.
A23	The EDF for produce consumption adds fruit consumption to vegetable consumption to provide a single produce EDF value (Equation 3.1-4a), therefore, the fraction of total produce grown locally shall be based on the higher fraction (fruits versus vegetables) for local productivity.	This is a modeling simplification.
A24	For element-specific or radionuclide-specific parameter development, when no data is available for a specific element or radionuclide, a non-zero value may be assumed, as appropriate.	Some parameters require non-zero values to prevent modeling errors. This assumption is only appropriate when no data is available and a negligible impact is expected.
A25	For intruder scenarios, it is assumed that it takes 20 hours to drill a well.	This assumption is based upon driller experience.

APPENDIX B

DEVELOPMENT OF SELECT PARAMETERS

APPENDIX B. DEVELOPMENT OF SELECT PARAMETERS

This appendix provides additional documentation to describe the development of the select parameters. Most of the parameters described within this appendix are based on the EPA's 2011 *Exposure Factors Handbook*, which provides extensive data from surveys. [EPA-600-R-090-052F] The EPA's 2011 *Exposure Factors Handbook* shall hereafter be referred to as the EPA Handbook.

A number of the values recommended vary relative to those reported in Revision 0 of this report. [SRR-CWDA-2013-00058, Rev. 0] The primary cause for this difference is that the initial report did not consistently apply the all of the assumptions (see Appendix A). The application of different assumptions resulted in different recommended values. Despite the inconsistent approach used to develop the previously recommended values, all of the assumptions used were reasonable and, therefore, appropriate for the intended use. In other words, calculations performed using the previous values are not invalidated by any new recommendations. However, future dose calculations should apply the most current values to ensure a consistent and defensible approach.

B1. Human Uptake Parameter: Water Consumption Rate

Section 3 of the EPA Handbook provides a comprehensive suite of tabulated data related to water consumption surveys. This data was used to update the recommendations for U_{H2O} and the fraction of consumed water that comes from the local water source $F_{local,H2O}$. Specifically, Tables 3-24 and 3-26 of the EPA Handbook were analyzed to develop appropriate parameter values for water ingestion dose calculations. [EPA-600-R-090-052F]

Table 3-23 from the EPA Handbook was also considered; however the data from this table was not explicitly used for data development. [EPA-600-R-090-052F] This table provided per capita data for water ingested from a community well. Ideally, this data set represents water intake values for the MOP and IHI receptors. However, comparing the median values from EPA Handbook Table 3-23 to the respective median values from Table 3-26 showed that there is a significant difference between the community well water intake values and the intake values from all water sources. Given this difference, the community well water intake values were ignored and an alternative approach was assumed for developing recommended water intake values.

EPA Handbook Table 3-26 was used as the starting point in the development of the recommended data values. This table provides the water intake values from all sources. Assuming that the MOP or IHI receptors would only consume water from the contaminated well is not consistent with the human receptor definitions provided in Section 1.1 of this report. Typical receptor behavior assumes that some water intake comes from other (i.e., uncontaminated) water sources. Data from EPA Table 3-24 shows water intake from bottle water sources. As a reasonably conservative approach, these bottled water intake values are assumed to represent any water intake that is not from the contaminated well.

The bottled water intake data does not include any median values, because less than 50% of those surveyed reported drinking any bottled water. Therefore, the ratio of the mean values (all

sources water intake versus the bottled water intake) was assumed as an appropriate approach for scaling the intake values. Table B1-1 summarizes the recommended values.

Table B1-1: Recommended Deterministic Values for Water Consumption Rates of Various Populations

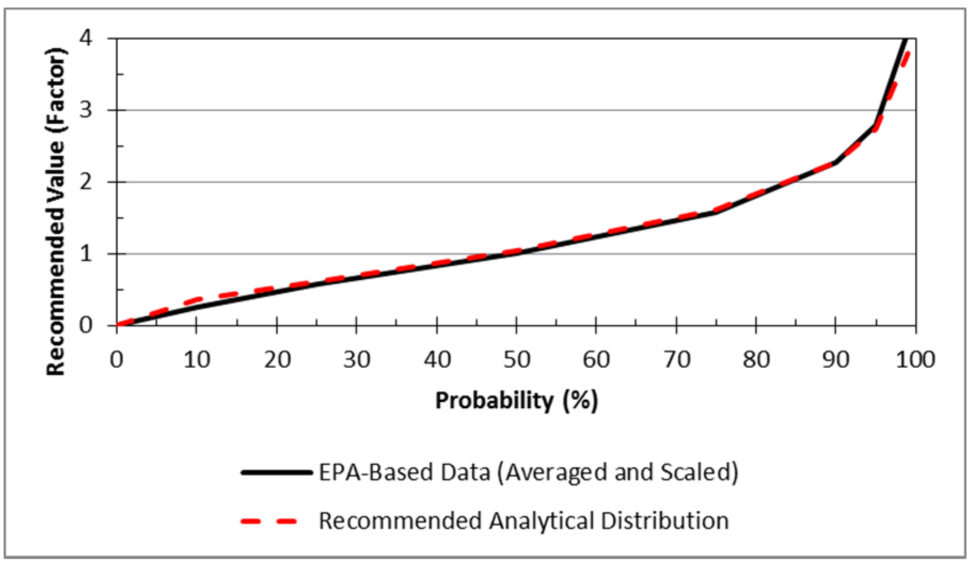
Age	Total Annual Water Consumption (L/yr) (U_{H2O})	Recommended Annual Water Consumption from Contaminated Well (L/yr) ($U_{H2O} \times F_{local,H2O}$)	Notes
Infant	108	89	Value for 1 to <2 year old
Child	209	166	Value for 6 to <11 year old
Adult	551	430	Value for ≥21 year old
Reference Person	439	340[a]	Value given for All ages

a Recommended value for deterministic modeling.

Based on this data, the recommended median value for U_{H2O} is 439 L/yr and the recommended median value for $U_{H2O} \times F_{local,H2O} = 340$ L/yr.

For distribution development, the respective infant, child, adult, and reference person data for contaminated water intake values were scaled to the respective median values then averaged across all age groups. An analytical distribution was developed using a stochastic element in GoldSim and simple trial-and-error to find parameter values that closely match the EPA-based recommended data values. The gamma distribution with a mean of 1.2 and a standard deviation of 0.8 was found to provide a close fit (see Figure B1-1).

Figure B1-1: Total Water Ingestion Rate – Distribution Curve



Finally, the values were truncated to between the 10th and 90th percentiles (based on the scaled and averaged EPA-based data) to ensure that sampled values are representative of typical and

reasonable human behavior. Therefore, the final recommended distribution for the uncertainty multiplier for water consumption is a gamma distribution with a mean of 1.2, a standard deviation of 0.8, a minimum of 0.26, and a maximum of 2.3.

B2. Human Uptake Parameter: Soil and Dust Consumption Rate

Table 5-1 of the EPA Handbook provides a number of recommended values for soil and dust consumption rates (U_{SOIL}). [EPA-600-R-090-052F] For Liquid Waste PAs, it is assumed that the receptors (MOP and IHI) are representative of the entire population. Therefore, as a reasonably conservative approach, the maximum value for the "General Population Central Tendency" in EPA Handbook Table 5-1 was assumed. The value of 100 mg/day was selected as the recommended value to use in deterministic modeling. This value was converted from mg/day to kg/yr by multiplying the consumption rate by 1.0E-06 kg/mg to get kg/day, then multiplying by 365.25 day/yr: 100 mg/day × 1.0E-06 kg/mg × 365.25 day/yr = 3.65E-02 kg/yr.

Table B2-1 provides recommended values for the four representative age groups.

Table B2-1: Recommended Deterministic Values for Soil Consumption Rates of Various Populations

Age	Total Annual Soil (Soil + Dust) Consumption (kg/yr) (U_{SOIL})	Notes
Infant	3.65E-02	General Population, Central Tendency (1 to <6 years)
Child	3.65E-02	General Population, Central Tendency (6 to <21 years)
Adult	1.83E-02	General Population, Central Tendency (Adult)
Reference Person	3.65E-02[a]	Conservatively assumes maximum of all three

a Recommended value for deterministic modeling.

Unlike the data reported for the water consumption distributions (as discussed in Section B1), the EPA Handbook provides very little insight to soil and dust consumption distributions. [EPA-600-R-090-052F] Therefore, a simple triangular distribution was applied that assumed a minimum value of one-half the deterministic rate (i.e., 50 mg/day) and a maximum value of twice the deterministic rate (i.e., 200 mg/day).

B3. Human Uptake Parameter: Produce Consumption Rate

Data from the EPA Handbook was used to update the recommendations for the rate of produce consumption (U_P). Specifically, Tables 9-7, 9-8, and 9-15 were analyzed to develop appropriate parameter values for the produce consumption rate. [EPA-600-R-090-052F]

Tables 9-7 and 9-8 of the EPA Handbook show the results of four surveys on consumption of fruits and vegetables, organized by gender and age group. [EPA-600-R-090-052F] Although the data used from these tables were mean values, the use of this data is conservative because inspection of other datasets indicated that the mean values are higher than the respective median values.

For each set of values, the total produce consumption rate was determined by adding the fruit intake rate to the vegetable intake rate. Gender-specific values were then combined using an assumed population distribution of 48% males to 52% females. Finally, for conservatism, the maximum value from each respective age group was selected as the representative value. Table B3-1 provides recommended values for the four representative age groups. These values were converted from g/day to kg/yr.

Table B3-1: Recommended Deterministic Values for Produce Consumption Rates of Various Populations

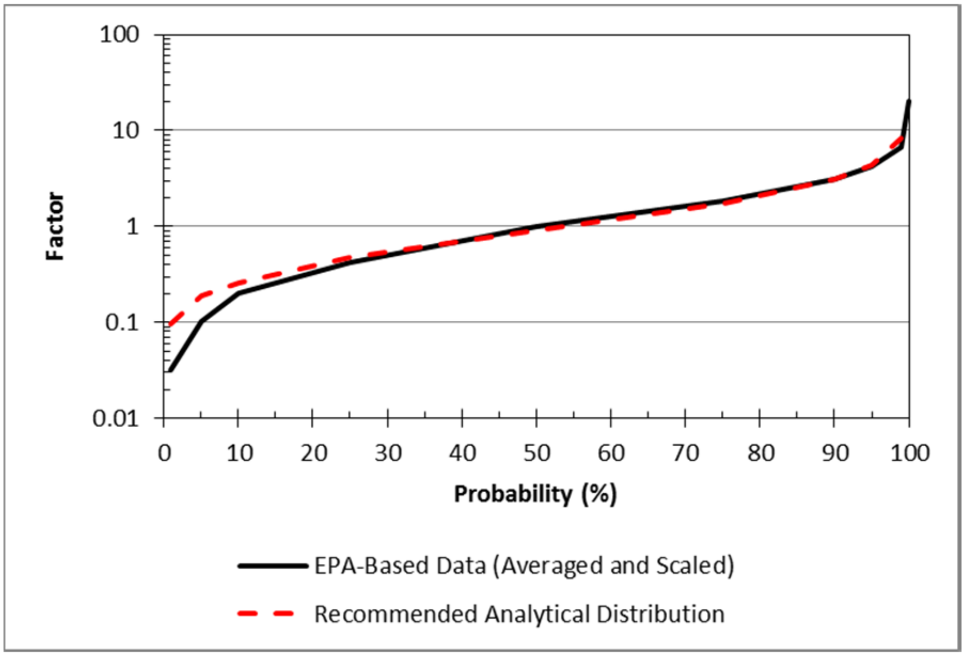
Age	Total Annual Produce (Fruit + Vegetable) Consumption (kg/yr) (U_P)	Notes
Infant	113	Value for less than 5 year old taken from 1994 data
Child	111	Value for less than 6-11 year old taken from 1995 data
Adult	156	Value for less than 51-64 year old taken from 1977-1978 data
Reference Person	132[a]	Value for all ages taken from 1995 data

a Recommended value for deterministic modeling.

Based on this data, the recommended median value for U_P is 132 kg/yr.

For distribution development, the respective infant, child, adult, and all ages data from EPA Table 9-15 were scaled to the respective values and averaged across all age groups. An analytical distribution was developed using a stochastic element in GoldSim and simple trial-and-error to find parameter values that closely match the EPA-based data. The log-normal distribution with a geometric mean of 0.9 and a geometric standard deviation of 2.6 was found to have a close fit (see Figure B3-1).

Figure B3-1: Total Produce Consumption Rate – Distribution Curve



Finally, the values were truncated to between the 10th and 90th percentiles (based on the scaled and averaged EPA-based data) to ensure that sampled values are representative of typical and reasonable human behavior. Therefore, the final recommended distribution for the uncertainty multiplier for produce consumption is a log-normal distribution with a geometric mean of 0.9, a geometric standard deviation of 2.6, a minimum of 0.2, and a maximum of 3.07.

B4. Human Uptake Parameter: Meat Consumption Rate

Data from the EPA Handbook were used to update the recommendations for the human consumption rate of terrestrial livestock meat (U_{MEAT}). Section 11 of the EPA Handbook provides an entire suite of tabulated data related to meat consumption. Specifically, Tables 11-7, 11-8, 11-9, and 11-18 were analyzed to develop appropriate parameter values for the meat consumption rate. [EPA-600-R-090-052F] These tables show the results of four surveys on consumption, organized by gender and age group. [EPA-600-R-090-052F]

Tables 11-7, 11-8, 11-9 of the EPA Handbook show the results of five surveys on consumption of a variety of meat products, organized by gender and age group. [EPA-600-R-090-052F] Although the data used from these tables were mean values, the use of this data is conservative because inspection of other datasets indicated that the mean values are higher than the respective median values.

For each set of values, the total terrestrial livestock meat consumption rate was determined by adding the intake rates of beef, pork, lamb, veal, game, frankfurters, sausages, lunch meats, spreads, and meat mixtures. Gender-specific values were then combined using an assumed population distribution of 48% males to 52% females. Finally, for conservatism, the maximum value from each respective age group was selected as the representative value. Table B4-1

provides recommended values for the four representative age groups. These values were converted from g/day to kg/yr.

Table B4-1: Recommended Deterministic Values for Terrestrial Livestock Meat Consumption Rates of Various Populations

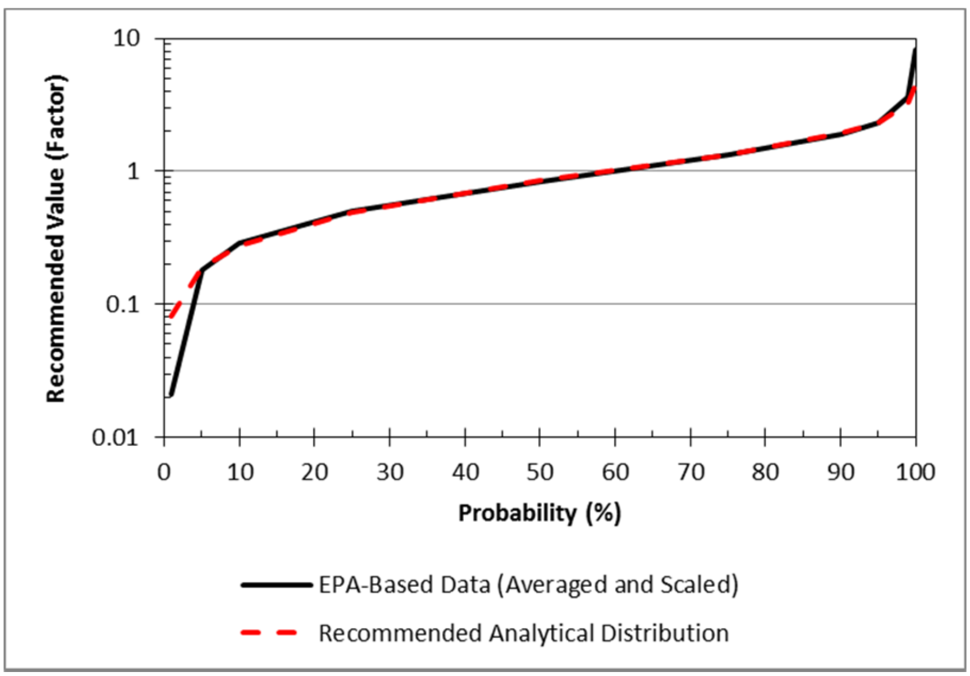
Age	Total Meat Consumption (kg/yr) (U_{MEAT})	Notes
Infant	27.2	Value for less than 5 year old taken from 1994 data
Child	52.2	Value for 9-11 year olds taken from 1977-1978 data
Adult	73.9	Value for 19 to 22 year olds taken from 1977-1978 data
Reference Person	61.4[a]	Value for all ages taken from 1977-1978 data

a Recommended value for deterministic modeling.

Based on this data, the recommended mean value for U_{MEAT} is 61.4 kg/yr.

For distribution development, the respective infant, child, adult, and all ages data from EPA Table 11-18 were scaled to the respective mean values and averaged across all age groups. An analytical distribution was developed using a stochastic element in GoldSim and simple trial-and-error to find parameter values that closely match the EPA-based data. The gamma distribution with a mean of 1.0 and a standard deviation of 0.69 was found to have a close fit (see Figure B4-1).

Figure B4-1: Total Terrestrial Livestock Meat Consumption Rate – Distribution Curve



Finally, the values were truncated to between the 10th and 90th percentiles (based on the scaled and averaged EPA-based data) to ensure that sampled values are representative of typical and reasonable human behavior. Therefore, the final recommended distribution for the uncertainty multiplier for terrestrial livestock meat consumption is a gamma distribution with a mean of 1.0, a standard deviation of 0.69, a minimum of 0.29, and a maximum of 1.88.

B5. Human Uptake Parameter: Milk Consumption Rate

Data from the EPA Handbook shall be used to update the recommendations for the human consumption rate of milk (U_{MILK}). Section 11 of the EPA Handbook provides a suite of tabulated data related to milk consumption. Specifically, Tables 11-4, 11-10, 11-11, and 11-12 of the EPA Handbook shall be analyzed to develop appropriate parameter values for the milk consumption rate. [EPA-600-R-090-052F]

Tables 11-10 through 11-12 of the EPA Handbook show the results of five surveys on consumption, organized by gender and age group. [EPA-600-R-090-052F] Although the data used from these tables were mean values, the use of this data is conservative because inspection of other datasets indicated that the mean values are higher than the respective median values.

For each set of values, the total fluid milk consumption rate was determined. Gender-specific values were then combined using an assumed population distribution of 48% males to 52% females. Finally, for conservatism, the maximum value from each respective age group was selected as the representative value. Table B5-1 provides recommended values for the four representative age groups. These values were converted from g/day to kg/yr.

Table B5-1: Recommended Deterministic Values for Milk Consumption Rates of Various Populations

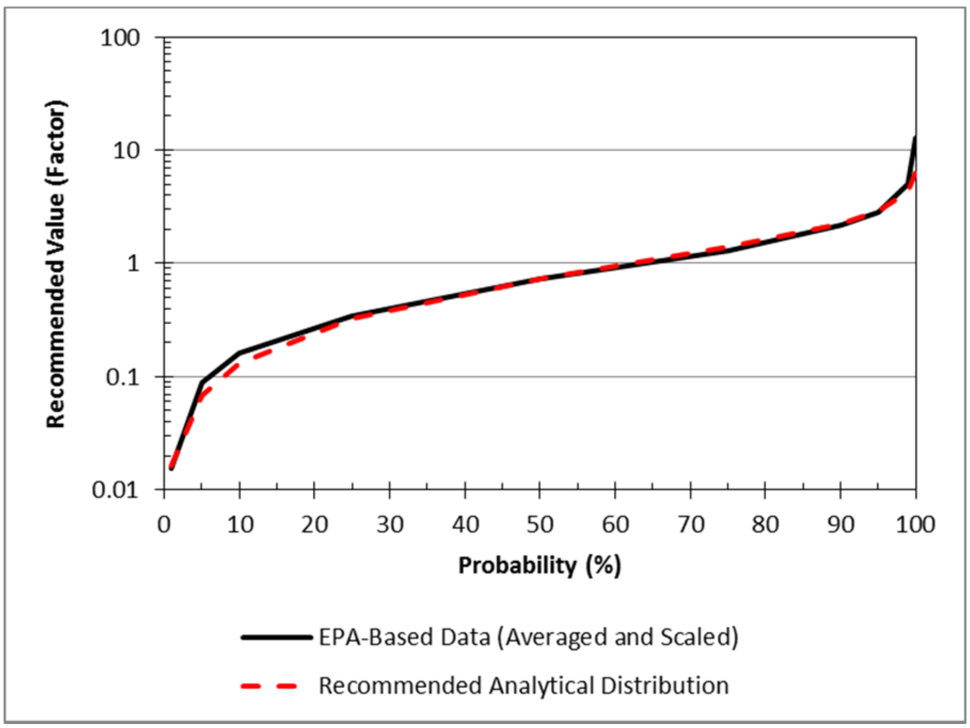
Age	Total Milk Consumption (kg/yr) (U_{MILK})	Notes
Infant	161	Value for less than 5 year old taken from 1995 data
Child	141	Value for 9-11 year olds taken from 1977-1978 data
Adult	135	Value for 19 to 22 year olds taken from 1977-1978 data
Reference Person	86[a]	Value for all ages taken from 1995 data

a Recommended value for deterministic modeling.

Based on this data, the recommended mean value for U_{MILK} is 86 kg/yr.

For distribution development, the respective infant, child, adult, and all ages data from EPA Table 11-4 were scaled to the respective mean values and averaged across all age groups. An analytical distribution was developed using a stochastic element in GoldSim and simple trial-and-error to find parameter values that closely match the EPA-based data. The gamma distribution with a mean of 1.0 and a standard deviation of 0.94 was found to have a close fit (see Figure B5-1).

Figure B5-1: Total Milk Consumption Rate – Distribution Curve



Finally, the values were truncated to between the 10th and 90th percentiles (based on the scaled and averaged EPA-based data) to ensure that sampled values are representative of typical and

reasonable human behavior. Therefore, the final recommended distribution for the uncertainty multiplier for milk consumption is a gamma distribution with a mean of 1.0, a standard deviation of 0.94, a minimum of 0.16, and a maximum of 2.16.

B6. Human Uptake Parameter: Poultry Consumption Rate

Data from the EPA Handbook were used to update the recommendations for the human consumption rate of poultry ($U_{POULTRY}$). Section 11 of the EPA Handbook provides an entire suite of tabulated data related to meat consumption. Specifically, Tables 11-7, 11-8, and 11-9 were analyzed to develop appropriate parameter values for the meat consumption rate. [EPA-600-R-090-052F] These tables show the results of four surveys on consumption, organized by gender and age group. [EPA-600-R-090-052F]

Tables 11-7, 11-8, and 11-9 of the EPA Handbook show the results of five surveys on consumption of a variety of meat products, organized by gender and age group. [EPA-600-R-090-052F] Although the data used from these tables were mean values, the use of this data is conservative because inspection of other datasets indicated that the mean values are higher than the respective median values.

For each set of values, the total poultry consumption rate was selected. Gender-specific values were then combined using an assumed population distribution of 48% males to 52% females. Finally, for conservatism, the maximum value from each respective age group was selected as the representative value. Table B6-1 provides recommended values for the four representative age groups. These values were converted from g/day to kg/yr.

Table B6-1: Recommended Deterministic Values for Poultry Consumption Rates of Various Populations

Age	Total Poultry Consumption (kg/yr) ($U_{POULTRY}$)	Notes
Infant	5.8	Value for less than 5 year old taken from 1994 data
Child	9.3	Value for 9-11 year olds taken from 1977-1978 data
Adult	12.8	Value for 19 to 22 year olds taken from 1977-1978 data
Reference Person	10.6[a]	Value for all ages taken from 1994 data

a Recommended value for deterministic modeling.

Based on this data, the recommended mean value for $U_{POULTRY}$ is 10.6 kg/yr.

The dose contribution from poultry is considered small relative to the other ingestion pathways (e.g., water, produce, etc.). Therefore, it is recommended that no sampling distribution be applied to this parameter. The deterministic value is appropriate to use for probabilistic modeling.

B7. Human Uptake Parameter: Egg Consumption Rate

Data from the EPA Handbook shall be used to update the recommendations for the human consumption rate of egg (U_{EGG}). Section 11 of the EPA Handbook provides a suite of tabulated data related to egg consumption. Specifically, Tables 11-10, 11-11, and 11-12 of the EPA Handbook shall be analyzed to develop appropriate parameter values for the egg consumption rate. [EPA-600-R-090-052F]

Tables 11-10 through 11-12 of the EPA Handbook show the results of five surveys on consumption, organized by gender and age group. [EPA-600-R-090-052F] Although the data used from these tables were mean values, the use of this data is conservative because inspection of other datasets indicated that the mean values are higher than the respective median values.

For each set of values, the total egg consumption rate was selected. Gender-specific values were then combined using an assumed population distribution of 48% males to 52% females. Finally, for conservatism, the maximum value from each respective age group was selected as the representative value. Table B7-1 provides recommended values for the four representative age groups. These values were converted from g/day to kg/yr.

Table B7-1: Recommended Deterministic Values for Egg Consumption Rates of Various Populations

Age	Total Milk Consumption (kg/yr) (U_{EGG})	Notes
Infant	7.3	Value for 1-2 year olds taken from 1977-1978 data
Child	7.2	Value for 9-11 year olds taken from 1977-1978 data
Adult	11.6	Value for 35 to 50 year olds taken from 1977-1978 data
Reference Person	7.3[a]	Value for all ages taken from 1987-1988 data

a Recommended value for deterministic modeling.

Based on this data, the recommended mean value for U_{EGG} is 7.3 kg/yr.

The dose contribution from egg is considered small relative to the other ingestion pathways (e.g., water, produce, etc.). Therefore, it is recommended that no sampling distribution be applied to this parameter. The deterministic value is appropriate to use for probabilistic modeling.

B8. Human Uptake Parameter: Fish Consumption

Data from the EPA Handbook were used to update the recommendations for the human consumption rate of fish (U_{FISH}). Section 10 of the EPA Handbook provides an entire suite of tabulated data related to fish consumption. Specifically, Tables 10-13 and 10-23 were analyzed to develop appropriate parameter values for the fish consumption rate. [EPA-600-R-090-052F] The data in Table 10-13 shows total fish consumption, organized by gender and age group. [EPA-600-R-090-052F]

Gender-specific values were combined using an assumed population distribution of 48% males to 52% females. For conservatism, values were weighted based on a comparison of the total (i.e.

Overall) demographic category and the regional (i.e., South Atlantic) data. Table B8-1 provides recommended values for the four representative age groups. These values were converted from g/day to kg/yr.

Table B8-1: Recommended Deterministic Values for Fish Consumption Rates of Various Populations

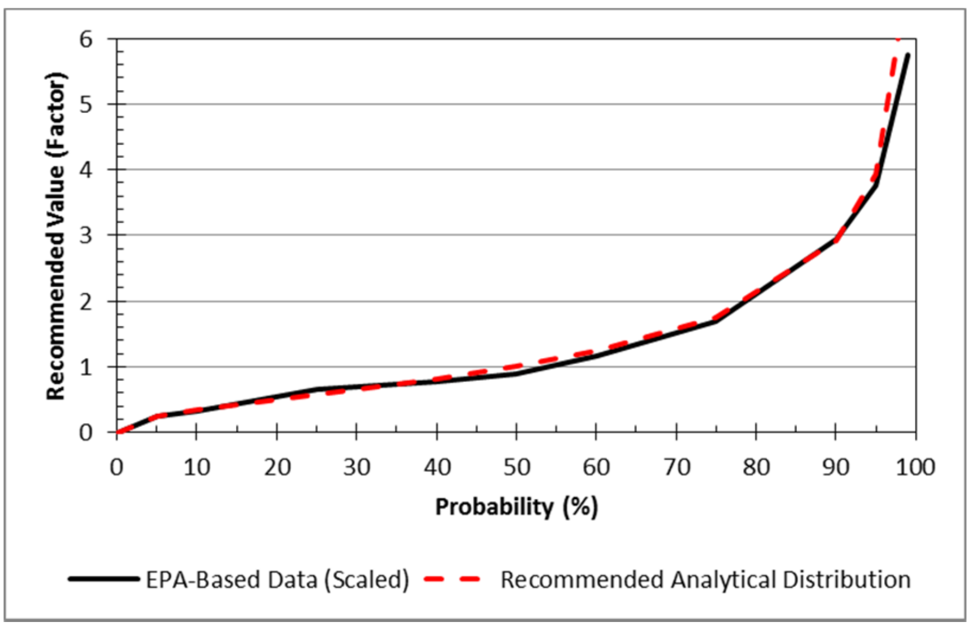
Age	Total Fish Consumption (kg/yr) (U_{FISH})	Notes
Infant	2.4	Value for 0-9 year olds used.
Child	3.9	Value for 10-19 year olds used.
Adult	8.4	Value for 60-69 year olds used.
Reference Person	5.6 [a]	Overall (all fish consumers) value.

a Recommended value for deterministic modeling.

Based on this data, the recommended mean value for U_{FISH} is 5.6 kg/yr.

For distribution development, the probability distribution data from EPA Handbook Table 10-23 was scaled relative to the geometric mean. An analytical distribution was developed using a stochastic element in GoldSim and simple trial-and-error to find parameter values that closely match the EPA-based data. The log-normal distribution with a geometric mean of 1.0 and a geometric standard deviation of 2.3 was found to have a close fit (see Figure B8-1).

Figure B8-1: Total Fish Consumption Rate – Distribution Curve



Finally, the values were truncated to between the 10th and 90th percentiles (based on the scaled EPA-based data) to ensure that sampled values are representative of typical and reasonable human behavior. Therefore, the final recommended distribution for the uncertainty multiplier for

fish consumption is a log-normal distribution with a geometric mean of 1.0, a geometric standard deviation of 2.3, a minimum of 0.33, and a maximum of 2.93.

B9. Human Uptake Parameter: Inhalation Rate

Data from the EPA Handbook was used to update the recommendations for the human inhalation rate (U_{AIR}). EPA Handbook Tables 6-1, 6-14, and 6-15 were used to develop appropriate parameter values for the inhalation rate. [EPA-600-R-090-052F] EPA Handbook Table 6-1 shows the mean inhalation rates, by age groups. [EPA-600-R-090-052F] Table B9-1 provides recommended values for the four representative age groups. These values were converted from m^3/day to m^3/yr.

Table B9-1: Recommended Deterministic Values for Human Inhalation Rates of Various Populations

Age	Inhalation Rate (m^3/yr) (U_{AIR})	Notes
Infant	2,922	Value for 1 to <2 year olds.
Child	4,383	Value for 6 to <11 year olds.
Adult	5,844	Value for 6 to <11 year olds.
Reference Person	5,844[a]	Assumes the same value as the adult age group.

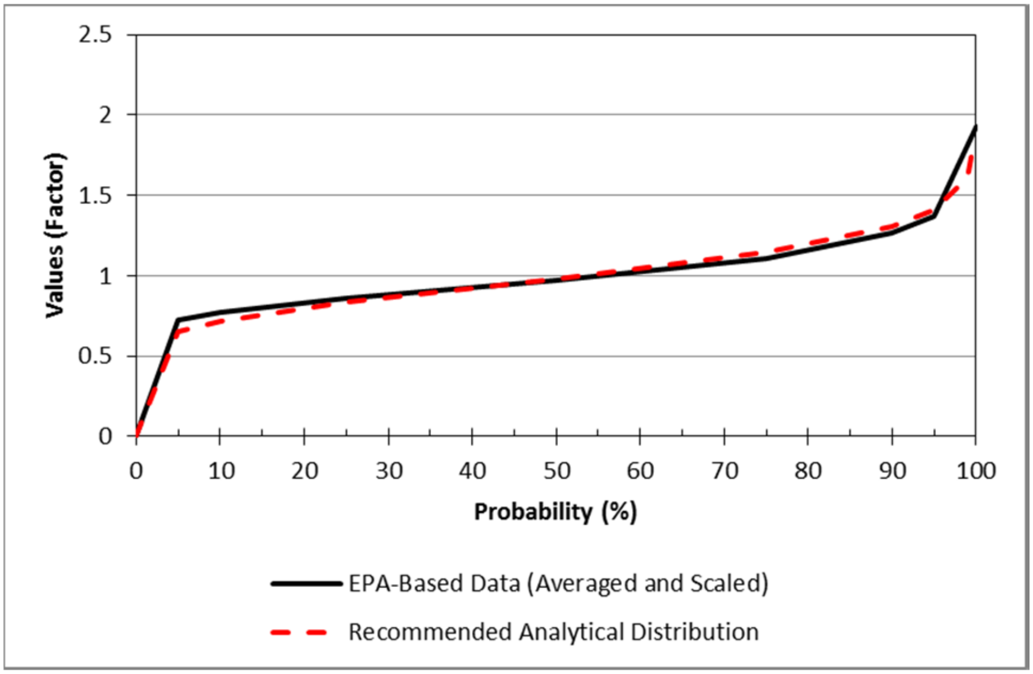
a Recommended value for deterministic modeling.

Based on this data, the recommended mean value for U_{AIR} is 5,844 m^3/yr.

For distribution development, the respective infant, child, adult, and all ages data from EPA Handbook Tables 6-14 and 6-15 were scaled to the respective mean values and averaged together across all age groups. Gender-specific values were combined using an assumed population distribution of 48% males to 52% females. An analytical distribution was developed using a stochastic element in GoldSim and simple trial-and-error to find parameter values that closely match the EPA-based data. The gamma distribution with a mean of 1.0 and a standard deviation of 0.23 was found to have a close fit (see Figure B9-1).

Finally, the values were truncated to between the 10^{th} and 90^{th} percentiles (based on the scaled and averaged EPA-based data) to ensure that sampled values are representative of typical and reasonable human behavior. Therefore, the final recommended distribution for the uncertainty multiplier for inhalation rates is a gamma distribution with a mean of 1.0, a standard deviation of 0.23, a minimum of 0.77, and a maximum of 1.27.

Figure B9-1: Human Inhalation Rate – Distribution Curve



B10. Fraction of Time in Garden

Table 16-100 of the EPA Handbook indicates that the average person spends 0.2 hr/day performing lawn and garden care. [EPA-600-R-090-052F] Given 24 hr/day, this results in a fractional value of 0.0083 (0.2 hr/day ÷ 24 hr/day). However, this value includes segments of the population that perform some amount of gardening as well as those who do no gardening at all, which is therefore inconsistent with the assumption that the MOP receptor has a garden. To account for this, the fractional value of 0.0083 is divided by 0.31 (because EPA Handbook Table 13-71 indicates that 31% of all households have gardens). This results in recommended a fractional value of 0.027 (0.0083 ÷ 0.31), which is equivalent to about 4.5 hours per week.

As a modeling simplification a triangular sampling distribution is assumed for probabilistic modeling, where the mode is equal to the recommended value (0.027), the minimum is one-half the recommended value (0.013), and the maximum is double the recommended value (0.054).

B11. Fraction of Time in Shower

EPA Handbook Table 16-1 provides recommended values for bathing and showering, organized by age group. For individuals less than 21 years of age, bathing and showering was counted separately. The maximum of either the bathing time or the showering time was assumed. Table B11-1 provides recommended values for the four representative age groups. These values were converted from minutes/day to a fractional value.

Table B11-1: Recommended Deterministic Values for the Fraction of Time Spent Bathing or Showering, Various Populations

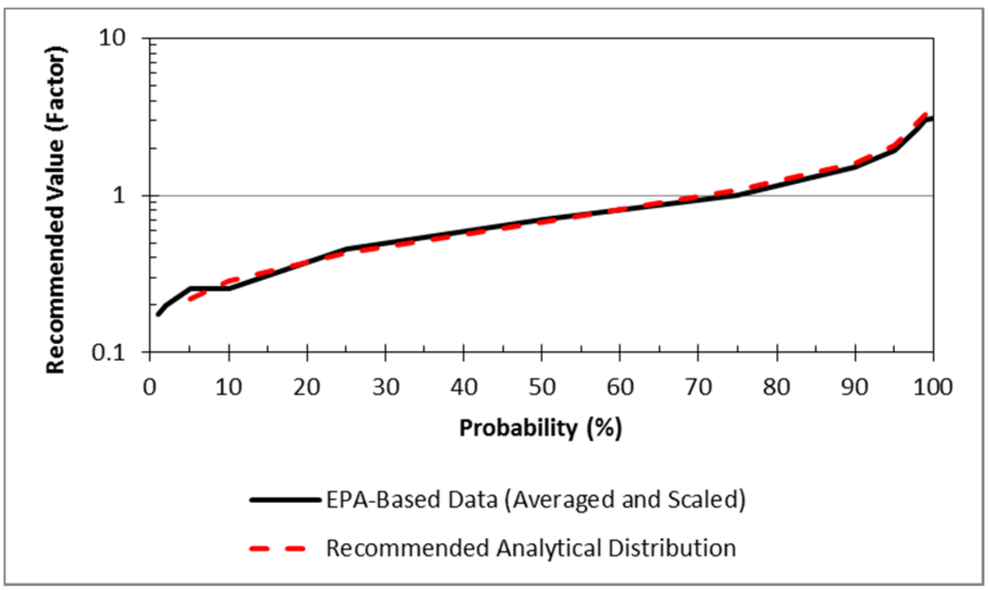
Age	Fraction of Time Spent Bathing or Showering ($F_{t,SHOWER}$)	Notes
Infant	1.6E-02	Value for 1 to <2 year olds.
Child	1.7E-02	Value for 6 to <11 year olds.
Adult	1.2E-02	Value for 18 to <65 year olds.
Reference Person	1.2E-02[a]	Assumes the same value as the adult age group.

a Recommended value for deterministic modeling.

Based on this data, the recommended mean value for $F_{t,SHOWER}$ is 1.2E-02.

For distribution development, the respective infant, child, adult, and all ages data from EPA Handbook Table 16-32 were scaled to the respective mean values and averaged together across all age groups. An analytical distribution was developed using a stochastic element in GoldSim and simple trial-and-error to find parameter values that closely match the EPA-based data. The log-normal distribution with a mean of 0.85 and a standard deviation of 0.65 was found to have a close fit (see Figure B11-1).

Figure B11-1: Fraction of Time Spent Bathing or Showering – Distribution Curve



Finally, the values were truncated to between the 10th and 90th percentiles (based on the scaled and averaged EPA-based data) to ensure that sampled values are representative of typical and reasonable human behavior. Therefore, the final recommended distribution for the uncertainty multiplier for the fraction of time spent bathing or showering is a log-normal distribution with a mean of 0.85, a standard deviation of 0.65, a minimum of 0.25, and a maximum of 1.52.

B12. Fraction of Time Swimming

Table 16-1 of the EPA Handbook provides age-dependent recommendations for minutes per month spent swimming; however the values recommended for the adult swimming pattern is based on median data rather than the more appropriate mean data. [EPA-600-R-090-052F] To correct for this, the distribution values for 18 to 64 year olds (from EPA Handbook Table 16-42) were input into a GoldSim stochastic element and sampled 10,000 times. The resulting mean value was assumed. This same approach was applied to determine the mean value for the all ages group.

Table B12-1 provides recommended values for the four representative age groups. These values were converted from minutes/month to a fractional value.

Table B12-1: Recommended Deterministic Values for the Fraction of Time Spent Swimming, Various Populations

Age	Fraction of Time Spent Swimming ($F_{t,SWIM}$)	Notes
Infant	2.4E-03	Value for 1 to <2 year olds.
Child	3.4E-03	Value for 6 to <11 year olds.
Adult	1.2E-03	Value for 18 to 64 year olds (based on sampling the statistical data in EPA Table 16-42).
Reference Person	1.7E-03 [a]	Value for all ages (based on sampling the statistical data in EPA Table 16-42).

a Recommended value for deterministic modeling.

Based on this data, the recommended mean value for $F_{t,SWIM}$ is 1.7E-03.

For distribution development, a simple triangular distribution is assumed. As a probabilistic multiplier, the recommended mode is 1.0, the minimum is 0, and the maximum is 3.3 (which is equivalent to 181 minutes per month when scaled by the recommended deterministic value).

B13. Fraction of Time Spent Drilling

This dose calculation methodology assumes that it takes 20 hours to install a well. Given that there are 8,766 hours per year this is equivalent to a fractional value of 2.3E-03. As a modeling simplification, a triangular distribution is assumed with a minimum equal to 2 hours and a maximum of 40 hours (i.e., as a multiplier, the mode is 1.0, the minimum is 0.1 and the maximum is 2.0).

B14. Well Depth

In the current Liquid Waste PAs, GoldSim models use two separate stochastic elements to determine well depths: “WellDepth” and “CompletionStratum”. These parameters were only used when the GoldSim model was used to simulate transport.

The WellDepth element was used for the IHI calculations to determine the concentration of contaminants from drill cuttings. In this case, a shallower depth gives a higher dose because the

contaminants are more concentrated within the drill cuttings. This input conservatively assumed a single discrete value of 100 feet (30.5 m) for the well depth, such that the stochastic parameter did not actually sample a distribution. This 100-foot value was a conservative assumption because more than 85% of the wells within and near the Savannah River Site were drilled to deeper depths. [SRS-REG-2007-00029, Rev. 0, SRR-CWDA-2010-00054, Rev. 0]

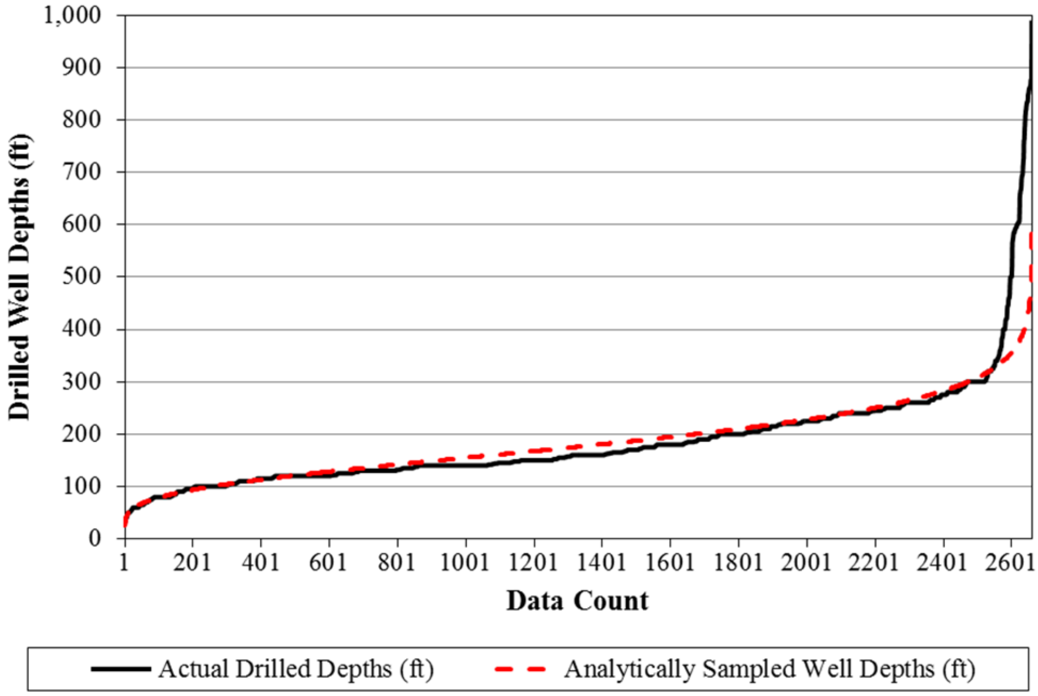
Alternatively, the CompletionStratum element in GoldSim was used to modify the groundwater concentrations for the MOP and Chronic IHI dose calculations based on well depths. This modifier was determined based on appropriate modeling results for aquifer flow and transport, which showed that contaminant concentrations in the Gordon Aquifer was generally much lower than in the Upper Three Runs Aquifer. Instead of estimating an actual well depth, however, the CompletionStratum element discretely sampled the probability of a well depth reaching a specific aquifer, and then was used to modify the modeled concentrations accordingly.

Realistically, it would be appropriate to assume that both an IHI well and the 100-meter well would be drilled to similar depths. This is because the relative distance between a 100-meter well and a 1-meter well is not significant with respect to groundwater levels. As a modeling simplification, it is recommended that the modeling approach be modified to apply a single sampling distribution for both the 1-meter and the 100-meter well depths.

Further, to determine an appropriate sampling approach, an evaluation was performed using well depth data from over 2,600 wells drilled within and near the boundary of the Savannah River Site. Based on this data analysis, well depths should be sampled along a gamma distribution, with a mean value of 185 feet (55.8 m), a minimum depth of 30 feet (9.1 m), a maximum depth of 990 feet (302 m). Figure B14-1 shows the actual well depths (sorted) versus results based on the recommended sampling distribution. This shows that the recommended sampling would better reflect actual well depth drilling results. The depth of 100 feet (30.5 m) is still recommended for deterministic modeling to maintain an appropriate level of conservatism.

For implementation in GoldSim, it is recommended to use a stochastic modeling element as a multiplier. The deterministic value should be set to 1.0 (which would be multiplied by the 100 foot value as a data input element). The truncated gamma distribution for sampling would then be set to a mean of 1.85 (100 ft × 1.85 = 185 ft), a minimum of 0.3 (100 ft × 0.3 = 30 ft), and a maximum of 9.9 (100 ft × 9.9 = 990 ft). The best fit was found by using a recommended standard deviation of 0.75 (100 ft × 0.75 = 75 ft).

Figure B14-1: Well Depth Sampling Comparison



The analytically sampled well depths were then screened for comparison to a previously established discrete well depth distribution (described in General Separations Area Well Drilling Probabilities). [SRS-REG-2007-00029] The previous distribution determined that 13% of past wells were drilled into the Upper Zone of the Upper Three Runs (UTR) Aquifer (i.e., less than or equal to 109 feet deep), 44% into the Lower Zone of the UTR Aquifer (between 109 and 170 feet deep), and 43% into the Gordon Aquifer (greater than or equal to 170 feet deep).

With the revised recommended sampling distribution for well depth, using 109 feet and 170 feet as the respective aquifer thresholds results in selecting the Gordon Aquifer 53% of the time. Because the Gordon aquifer is assumed to return lower concentrations than the other aquifers, this value is non-conservative. To address this non-conservatism, it is recommended that the screening depths be adjusted to better capture the recommended aquifer distribution as follows: the Upper Zone of the UTR Aquifer should be less than or equal to 106 feet deep, the Lower Zone of the UTR Aquifer should be between 106 and 188 feet deep, and the Gordon Aquifer should be greater than or equal to 188 feet deep. By making this screening depth adjustment, the well depth distribution again reflects the expected aquifer distributions of 13%, 44% and 43% for the Upper UTR, Lower UTR, and the Gordon Aquifers, respectively.

B15. Additional Internal DCFs

Table 7.1-1 provided recommended ingestion and inhalation DCFs for the assumed reference person. To facilitate future modeling of alternative conceptual scenarios, the following provides additional DCFs for specific age groups (i.e., Infant, Child, and Adult). As with Table 7.1-1, some nuclides shows duplicate entries for these DCFs where the first entry is the DCF for the specific radionuclide and the second entry (shaded) represents the sum of the parent and its

progeny that are assumed to be in secular equilibrium. Note that although this data is available, current PA and Special Analysis modeling does not include such alternative conceptual scenarios as the application would be inconsistent with current modeling assumptions.

Table B15-1: Alternative Internal DCFs

Nuclide	Internal DCFs (mrem/pCi)					
	Ingestion Infant	**Ingestion Child**	**Ingestion Adult**	**Inhalation Infant**	**Inhalation Child**	**Inhalation Adult**
	DCFing	*DCFing*	*DCFing*	*DCFinh*	*DCFinh*	*DCFinh*
Ac-225	8.99E-04	3.02E-04	1.43E-04	5.55E-02	3.96E-02	3.40E-02
Ac-227	2.47E-03	1.38E-03	1.19E-03	1.28E+00	6.59E-01	5.77E-01
Ac-227 [a]	6.81E-03	3.15E-03	1.61E-03	1.41E+00	7.46E-01	6.53E-01
Ac-228	9.25E-06	2.89E-06	1.40E-06	1.98E-04	7.29E-05	5.96E-05
Ag-108m	4.11E-05	1.59E-05	8.70E-06	2.36E-04	1.48E-04	1.49E-04
Al-26	7.84E-05	2.62E-05	1.29E-05	6.66E-04	4.14E-04	4.22E-04
Am-241	1.39E-03	8.21E-04	7.55E-04	6.59E-01	3.74E-01	3.57E-01
Am-242	8.07E-06	2.39E-06	1.11E-06	2.61E-04	8.92E-05	7.99E-05
Am-242m	1.11E-03	7.36E-04	7.03E-04	5.66E-01	3.47E-01	3.39E-01
Am-242m [a]	1.35E-03	8.11E-04	7.40E-04	6.30E-01	3.69E-01	3.59E-01
Am-243	1.37E-03	8.18E-04	7.51E-04	6.48E-01	3.70E-01	3.54E-01
Am-243 [a]	1.39E-03	8.24E-04	7.54E-04	6.48E-01	3.70E-01	3.54E-01
Ar-39	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
At-217	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
At-218	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba-133	2.33E-05	1.74E-05	5.70E-06	7.44E-05	4.26E-05	4.14E-05
Ba-137m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bi-210	3.60E-05	1.06E-05	4.85E-06	1.01E-03	5.88E-04	5.40E-04
Bi-210m a	3.37E-04	1.10E-04	5.55E-05	7.25E-02	4.00E-02	3.96E-02
Bi-210m [a]	3.37E-04	1.10E-04	5.55E-05	7.25E-02	4.00E-02	3.96E-02
Bi-211	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bi-212	6.66E-06	1.88E-06	9.66E-07	2.40E-04	1.51E-04	1.36E-04
Bi-213	5.14E-06	1.43E-06	7.33E-07	2.38E-04	1.44E-04	1.31E-04
Bi-214	2.78E-06	7.77E-07	4.14E-07	1.32E-04	6.81E-05	6.36E-05
Bk-249	1.07E-05	5.07E-06	3.67E-06	3.70E-03	1.92E-03	1.55E-03
C-14	5.96E-06	2.96E-06	2.15E-06	4.00E-05	2.34E-05	2.28E-05
Ca-41	2.26E-06	2.06E-06	8.40E-07	1.65E-06	1.42E-06	8.51E-07
Cd-113m	2.09E-04	1.09E-04	8.66E-05	1.02E-03	5.07E-04	4.14E-04
Ce-144	1.44E-04	4.26E-05	1.94E-05	9.95E-04	2.89E-04	2.13E-04

Table 7.1-1: Alternative Internal DCFs (Continued)

Nuclide	Internal DCFs (mrem/pCi)					
	Ingestion Infant	Ingestion Child	Ingestion Adult	Inhalation Infant	Inhalation Child	Inhalation Adult
	DCFing	*DCFing*	*DCFing*	*DCFinh*	*DCFinh*	*DCFinh*
Cf-249	3.20E-03	1.72E-03	1.30E-03	1.59E+00	7.99E-01	6.22E-01
Cf-250	2.01E-03	8.58E-04	5.96E-04	9.73E-01	3.89E-01	2.79E-01
Cf-251	3.25E-03	1.75E-03	1.32E-03	1.62E+00	8.14E-01	6.33E-01
Cf-252	1.91E-03	6.88E-04	3.35E-04	8.07E-01	2.75E-01	1.36E-01
Cl-36	2.33E-05	7.07E-06	3.43E-06	2.42E-04	1.45E-04	1.48E-04
Cm-242	2.81E-04	8.73E-05	4.33E-05	7.66E-02	2.68E-02	2.39E-02
Cm-243	1.21E-03	6.18E-04	5.55E-04	5.55E-01	2.73E-01	2.59E-01
Cm-244	1.08E-03	5.18E-04	4.55E-04	5.00E-01	2.28E-01	2.11E-01
Cm-245	1.40E-03	8.44E-04	7.70E-04	6.62E-01	3.81E-01	3.64E-01
Cm-246	1.39E-03	8.36E-04	7.66E-04	6.62E-01	3.81E-01	3.63E-01
Cm-247	1.30E-03	7.73E-04	7.07E-04	6.07E-01	3.49E-01	3.33E-01
Cm-247 [a]	1.30E-03	7.74E-04	7.07E-04	6.07E-01	3.49E-01	3.33E-01
Cm-248	5.33E-03	3.16E-03	2.87E-03	2.44E+00	1.41E+00	1.34E+00
Co-60	9.92E-05	4.14E-05	1.27E-05	2.18E-04	1.27E-04	1.22E-04
Cs-134	5.81E-05	5.22E-05	7.14E-05	1.54E-04	8.58E-05	8.21E-05
Cs-135	1.14E-05	8.18E-06	9.81E-06	7.84E-05	4.74E-05	4.63E-05
Cs-137	4.59E-05	3.77E-05	5.03E-05	2.58E-04	1.53E-04	1.54E-04
Cs-137 [a]	4.59E-05	3.77E-05	5.03E-05	2.58E-04	1.53E-04	1.54E-04
Eu-152	2.68E-05	9.51E-06	4.96E-06	9.73E-04	4.44E-04	3.45E-04
Eu-154	4.33E-05	1.45E-05	7.29E-06	1.28E-03	5.33E-04	3.96E-04
Eu-155	8.29E-06	2.58E-06	1.23E-06	1.86E-04	6.77E-05	4.59E-05
Fr-221	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fr-223	6.29E-05	1.85E-05	8.81E-06	8.44E-05	5.62E-05	4.92E-05
Gd-152	4.29E-04	1.96E-04	1.52E-04	1.98E-01	8.70E-02	7.03E-02
H-3	2.04E-07	9.07E-08	7.07E-08	2.32E-06	1.03E-06	1.07E-06
I-129	8.14E-04	7.10E-04	4.00E-04	5.92E-04	4.77E-04	4.00E-04
K-40	1.55E-04	4.70E-05	2.28E-05	5.29E-04	3.17E-04	3.28E-04
Kr-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lu-174	6.81E-06	2.18E-06	1.05E-06	1.18E-04	4.07E-05	2.67E-05
Mo-93	2.40E-05	1.36E-05	1.07E-05	1.45E-05	8.73E-06	8.73E-06
Mo-93m	2.10E-06	7.70E-07	4.44E-07	2.53E-06	8.33E-07	7.96E-07
Na-22	5.44E-05	2.04E-05	1.17E-05	2.16E-04	1.21E-04	1.17E-04
Nb-93m	3.52E-06	1.04E-06	4.77E-07	1.58E-05	7.55E-06	7.73E-06

Table 7.1-1: Internal and External DCFs (Continued)

Nuclide	Internal DCFs (mrem/pCi)					
	Ingestion Infant	**Ingestion Child**	**Ingestion Adult**	**Inhalation Infant**	**Inhalation Child**	**Inhalation Adult**
	DCFing	*DCFing*	*DCFing*	*DCFinh*	*DCFinh*	*DCFinh*
Nb-94	3.60E-05	1.27E-05	6.40E-06	3.05E-04	1.90E-04	1.89E-04
Ni-59	1.25E-06	4.14E-07	2.31E-07	7.33E-06	3.30E-06	3.38E-06
Ni-63	3.15E-06	1.04E-06	5.74E-07	1.80E-05	8.07E-06	8.25E-06
Np-237	7.84E-04	4.26E-04	3.96E-04	3.49E-01	1.86E-01	1.84E-01
Np-237 [a]	8.10E-04	4.33E-04	3.99E-04	3.49E-01	1.86E-01	1.84E-01
Np-238	2.23E-05	6.99E-06	3.31E-06	2.96E-05	1.38E-05	1.29E-05
Np-239	2.17E-05	6.55E-06	3.01E-06	8.29E-06	4.88E-06	4.33E-06
Np-240	1.72E-06	5.14E-07	2.68E-07	7.96E-07	3.30E-07	3.13E-07
Np-240m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pa-231	3.03E-03	2.09E-03	1.77E-03	1.51E+00	9.77E-01	8.51E-01
Pa-233	2.54E-05	7.73E-06	3.57E-06	3.23E-05	1.93E-05	1.69E-05
Pa-234	9.92E-06	3.18E-06	1.55E-06	3.64E-06	1.57E-06	1.47E-06
Pa-234m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-209	1.41E-06	4.03E-07	2.10E-07	5.33E-07	2.76E-07	2.58E-07
Pb-210	1.35E-02	7.22E-03	2.58E-03	4.26E-02	2.16E-02	2.23E-02
Pb-210 [a]	1.35E-02	1.68E-02	7.06E-03	7.55E-02	4.12E-02	4.02E-02
Pb-211	5.37E-06	1.54E-06	6.59E-07	1.01E-04	5.62E-05	5.03E-05
Pb-212	2.35E-04	7.55E-05	2.22E-05	1.22E-03	8.88E-04	7.59E-04
Pb-214	3.89E-06	1.14E-06	5.14E-07	1.04E-04	5.66E-05	5.92E-05
Pd-107	1.05E-06	3.12E-07	1.42E-07	4.81E-06	2.34E-06	2.44E-06
Pm-147	7.03E-06	2.09E-06	9.66E-07	1.27E-04	4.22E-05	2.58E-05
Po-210	3.26E-02	9.58E-03	4.48E-03	3.20E-02	1.90E-02	1.73E-02
Po-211	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-213	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-214	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-215	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-216	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-218	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pr-144	1.30E-06	3.54E-07	1.87E-07	2.76E-07	7.88E-08	8.07E-08
Pt-193	9.95E-07	2.91E-07	1.32E-07	5.33E-06	2.62E-06	2.69E-06
Pu-238	1.48E-03	9.03E-04	8.44E-04	7.07E-01	4.14E-01	4.00E-01
Pu-239	1.56E-03	1.00E-03	9.29E-04	7.55E-01	4.63E-01	4.40E-01

Table 7.1-1: Internal and External DCFs (Continued)

Nuclide	Internal DCFs (mrem/pCi)					
	Ingestion Infant	**Ingestion Child**	**Ingestion Adult**	**Inhalation Infant**	**Inhalation Child**	**Inhalation Adult**
	DCFing	*DCFing*	*DCFing*	*DCFinh*	*DCFinh*	*DCFinh*
Pu-240	1.56E-03	1.00E-03	9.29E-04	7.55E-01	4.63E-01	4.40E-01
Pu-241	2.14E-05	1.87E-05	1.75E-05	1.08E-02	8.81E-03	8.44E-03
Pu-242	1.48E-03	9.55E-04	8.84E-04	7.14E-01	4.40E-01	4.18E-01
Pu-243	2.32E-06	6.77E-07	3.16E-07	7.62E-07	3.42E-07	3.63E-07
Pu-244	1.53E-03	9.62E-04	8.81E-04	7.07E-01	4.33E-01	4.14E-01
Pu-244 [a]	1.56E-03	9.71E-04	8.85E-04	7.07E-01	4.33E-01	4.14E-01
Ra-223	4.07E-03	1.68E-03	3.81E-04	5.70E-02	4.03E-02	3.47E-02
Ra-224	2.41E-03	9.47E-04	2.39E-04	2.21E-02	1.56E-02	1.35E-02
Ra-225	4.44E-03	1.86E-03	3.69E-04	5.14E-02	3.61E-02	3.11E-02
Ra-226	3.53E-03	2.97E-03	1.04E-03	6.99E-02	3.85E-02	3.81E-02
Ra-226 [a]	3.54E-03	2.97E-03	1.04E-03	7.02E-02	3.86E-02	3.82E-02
Ra-228	2.09E-02	1.45E-02	2.58E-03	1.17E-01	6.07E-02	6.33E-02
Ra-228 [a]	2.50E-02	1.60E-02	3.11E-03	6.85E-01	2.69E-01	2.39E-01
Rb-87	3.96E-05	1.17E-05	5.66E-06	1.07E-04	6.33E-05	6.22E-05
Re-188	4.07E-05	1.05E-05	5.03E-06	1.64E-05	3.70E-06	2.47E-06
Rh-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-219	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-220	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ru-106	1.84E-04	5.55E-05	2.60E-05	5.14E-04	2.62E-04	2.68E-04
S-35	3.20E-06	9.92E-07	4.85E-07	1.33E-05	8.55E-06	7.55E-06
Sb-125	2.28E-05	7.92E-06	4.26E-06	9.10E-05	5.03E-05	4.81E-05
Sb-126	5.85E-05	2.00E-05	9.92E-06	2.98E-05	1.60E-05	1.47E-05
Sb-126m	8.81E-07	2.60E-07	1.41E-07	3.13E-07	9.10E-08	8.84E-08
Sc-46	2.95E-05	1.07E-05	5.44E-06	1.24E-04	4.33E-05	2.76E-05
Se-79	9.77E-05	4.77E-05	1.01E-05	4.48E-05	2.59E-05	2.51E-05
Sm-147	5.07E-04	2.36E-04	1.83E-04	2.38E-01	1.05E-01	8.55E-02
Sm-151	2.39E-06	7.36E-07	3.66E-07	9.92E-05	4.29E-05	3.43E-05
Sn-121	6.33E-06	1.86E-06	8.51E-07	2.04E-06	1.17E-06	1.05E-06
Sn-121m	1.03E-05	3.07E-06	1.43E-06	1.02E-04	5.99E-05	5.88E-05
Sn-126	1.14E-04	3.65E-05	1.78E-05	9.81E-04	5.99E-04	6.14E-04
Sn-126 [a]	1.23E-04	3.96E-05	1.93E-05	9.85E-04	6.02E-04	6.16E-04
Sr-90	2.68E-04	2.21E-04	1.02E-04	9.92E-04	5.88E-04	6.07E-04
Sr-90 [a]	3.42E-04	2.42E-04	1.12E-04	1.01E-03	5.95E-04	6.13E-04

Table 7.1-1: Internal and External DCFs (Continued)

Nuclide	Internal DCFs (mrem/pCi)					
	Ingestion Infant	**Ingestion Child**	**Ingestion Adult**	**Inhalation Infant**	**Inhalation Child**	**Inhalation Adult**
	DCFing	*DCFing*	*DCFing*	*DCFinh*	*DCFinh*	*DCFinh*
Tc-99	1.76E-05	4.85E-06	2.38E-06	8.92E-05	5.37E-05	5.25E-05
Te-125m	2.34E-05	6.88E-06	3.22E-06	2.87E-05	1.94E-05	1.67E-05
Th-227	2.64E-04	8.55E-05	3.37E-05	6.99E-02	4.77E-02	4.14E-02
Th-228	1.37E-03	5.07E-04	2.66E-04	5.44E-01	1.91E-01	1.61E-01
Th-229	3.85E-03	2.31E-03	1.85E-03	1.91E+00	1.08E+00	8.84E-01
Th-229 [a]	9.19E-03	4.48E-03	2.36E-03	2.02E+00	1.15E+00	9.50E-01
Th-230	1.52E-03	9.10E-04	7.92E-04	7.36E-01	4.18E-01	3.77E-01
Th-231	9.21E-06	2.72E-06	1.24E-06	3.00E-06	1.51E-06	1.40E-06
Th-232	1.69E-03	1.07E-03	8.55E-04	8.33E-01	4.96E-01	4.07E-01
Th-234	9.32E-05	2.76E-05	1.25E-05	9.07E-05	3.36E-05	3.18E-05
Tl-207	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-208	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl-209	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-232	3.04E-03	2.12E-03	1.24E-03	2.43E-01	1.40E-01	1.44E-01
U-232 [a]	7.06E-03	3.65E-03	1.76E-03	8.11E-01	3.48E-01	3.19E-01
U-233	5.11E-04	2.89E-04	1.89E-04	7.03E-02	3.89E-02	3.81E-02
U-234	4.96E-04	2.76E-04	1.83E-04	6.92E-02	3.81E-02	3.74E-02
U-235	4.77E-04	2.64E-04	1.73E-04	6.29E-02	3.40E-02	3.38E-02
U-235 [a]	4.87E-04	2.67E-04	1.74E-04	6.29E-02	3.40E-02	3.38E-02
U-236	4.66E-04	2.59E-04	1.72E-04	6.44E-02	3.49E-02	3.46E-02
U-238	4.48E-04	2.50E-04	1.65E-04	5.96E-02	3.22E-02	3.21E-02
U-238 [a]	5.51E-04	2.81E-04	1.79E-04	5.97E-02	3.22E-02	3.21E-02
U-240	2.95E-05	8.77E-06	4.03E-06	5.85E-06	2.52E-06	2.45E-06
W-181	2.01E-06	6.62E-07	3.20E-07	2.66E-06	1.26E-06	1.20E-06
W-185	1.21E-05	3.59E-06	1.64E-06	2.75E-05	1.79E-05	1.57E-05
W-188	5.70E-05	1.69E-05	7.73E-06	1.20E-04	6.73E-05	6.36E-05
Y-90	7.40E-05	2.18E-05	9.92E-06	1.89E-05	6.59E-06	6.55E-06
Zr-93	2.77E-06	2.11E-06	3.96E-06	1.73E-05	3.55E-05	8.92E-05

Sources: DOE-STD-1196-2011, Tables A-1 and A2.

a Value shows the sum of a parent radionuclide plus daughter products assumed to be at secular equilibrium. See Table 7.1-2 for a summary of which radionuclides were used in this assumption.

APPENDIX C

BIOSPHERE DOSE CONVERSION FACTORS FROM REVISED DOSE CALCULATION METHODOLOGY

APPENDIX C. BIOSPHERE DOSE CONVERSION FACTORS FROM REVISED DOSE CALCULATION METHODOLOGY

This appendix uses unit concentrations (i.e., 1.0 pCi/L) for each radionuclide to calculate biosphere dose conversion factors (BDCFs) for all groundwater pathways considered. Note that due to soil buildup (see Eq. 3.1-3b), some BDCFs vary over time. For such BDCFs, the highest value over time is reported.

Table C-1: Biosphere Dose Conversion Factors for Ingestion Pathways for Select Radionuclides

Radio-nuclide	Water Ingestion	Soil Ingestion	Fruit and Vegetable Ingestion	Meat Ingestion	Milk Ingestion	Poultry Ingestion	Egg Ingestion	Fish Ingestion
	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)
Ac-227	7.85E-01	1.34E-03	6.40E-03	4.96E-05	2.74E-06	7.93E-07	4.66E-07	3.04E-02
Ag-108m	3.71E-03	3.04E-07	3.02E-05	1.75E-06	1.02E-06	8.64E-07	1.89E-07	6.31E-04
Al-26	5.78E-03	1.44E-05	4.81E-05	1.37E-06	2.08E-07	4.09E-24	3.58E-24	4.56E-04
Am-241	3.00E-01	7.15E-04	2.45E-03	2.36E-05	2.19E-08	3.41E-07	1.50E-07	1.11E-01
Am-242m	2.92E-01	6.74E-04	2.39E-03	2.30E-05	2.14E-08	3.28E-07	1.44E-07	1.09E-01
Am-243	2.98E-01	7.24E-04	2.44E-03	2.35E-05	2.18E-08	3.42E-07	1.50E-07	1.11E-01
Bi-210m	2.53E-02	6.15E-05	1.66E-03	4.18E-06	4.58E-06	6.59E-07	1.54E-06	5.88E-04
C-14	7.96E-04	6.53E-08	8.64E-06	4.17E-06	1.75E-06	3.49E-25	3.06E-25	3.70E-06
Cf-249	5.61E-01	1.33E-03	4.59E-03	3.54E-06	1.47E-07	6.38E-07	3.75E-07	2.17E-02
Cf-251	5.71E-01	1.38E-03	4.67E-03	3.61E-06	1.49E-07	6.53E-07	3.84E-07	2.21E-02
Cl-36	1.56E-03	1.28E-08	2.32E-05	4.95E-06	5.19E-06	5.75E-09	4.53E-07	1.14E-04
Cm-243	2.26E-01	4.19E-04	1.86E-03	1.43E-06	7.90E-07	2.35E-07	1.38E-07	1.05E-02
Cm-244	1.90E-01	3.05E-04	1.56E-03	1.20E-06	6.63E-07	1.88E-07	1.11E-07	8.83E-03
Cm-245	3.04E-01	7.39E-04	2.50E-03	1.92E-06	1.06E-06	3.49E-07	2.05E-07	1.41E-02
Cm-246	3.03E-01	7.36E-04	2.49E-03	1.92E-06	1.06E-06	3.48E-07	2.05E-07	1.41E-02
Cm-247	2.80E-01	6.80E-04	2.30E-03	1.77E-06	9.76E-07	3.21E-07	1.89E-07	1.30E-02
Cm-248	1.14E+00	2.76E-03	9.34E-03	7.18E-06	3.96E-06	1.30E-06	7.66E-07	5.28E-02
Co-60	6.90E-03	1.64E-06	6.58E-05	4.85E-07	1.36E-07	8.27E-07	2.46E-08	8.12E-04
Cs-135	3.32E-03	2.73E-07	2.75E-05	1.15E-05	2.67E-06	1.05E-06	1.37E-07	1.29E-02
Cs-137	1.67E-02	1.35E-06	1.38E-04	5.80E-05	1.34E-05	5.27E-06	6.87E-07	6.48E-02
Eu-152	2.19E-03	3.08E-06	2.07E-05	7.13E-09	1.17E-08	7.03E-10	1.24E-11	4.41E-04
Eu-154	3.28E-03	3.66E-06	3.01E-05	1.06E-08	1.75E-08	9.91E-10	1.74E-11	6.61E-04

Table C-1: Biosphere Dose Conversion Factors for Ingestion Pathways for Select Radionuclides (Continued)

Radio-nuclide	Water Ingestion	Soil Ingestion	Fruit and Vegetable Ingestion	Meat Ingestion	Milk Ingestion	Poultry Ingestion	Egg Ingestion	Fish Ingestion
	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)
Eu-155	5.68E-04	3.99E-07	4.97E-06	1.82E-09	3.00E-09	1.56E-10	2.74E-12	1.14E-04
Gd-152	6.70E-02	1.63E-04	7.00E-04	2.24E-07	3.65E-07	2.61E-08	4.59E-10	3.11E-03
H-3	2.64E-05	0.00E+00	2.15E-07	1.51E-23	6.90E-08	0.00E+00	0.00E+00	4.09E-08
I-129	1.52E-01	1.25E-06	4.96E-03	2.70E-04	2.09E-04	1.93E-07	4.67E-05	7.08E-03
K-40	1.03E-02	4.24E-07	9.83E-05	3.37E-05	1.33E-05	4.86E-07	1.06E-06	5.12E-02
Mo-93	3.91E-03	9.35E-06	2.26E-04	1.47E-06	1.44E-06	1.79E-07	5.58E-07	1.15E-05
Nb-93m	2.24E-04	1.89E-07	1.92E-06	9.26E-12	1.61E-11	9.49E-12	2.78E-11	1.04E-04
Nb-94	2.81E-03	3.26E-06	2.46E-05	1.17E-10	2.02E-10	1.28E-10	3.73E-10	1.30E-03
Ni-59	1.00E-04	5.76E-09	8.46E-07	7.94E-08	1.67E-08	1.17E-11	1.02E-09	3.26E-06
Ni-63	2.49E-04	1.43E-08	2.10E-06	1.97E-07	4.14E-08	2.89E-11	2.54E-09	8.10E-06
Np-237	1.59E-01	3.91E-06	1.30E-03	2.50E-05	1.38E-07	1.09E-07	6.41E-08	5.16E-03
Pa-231	7.04E-01	1.73E-05	5.73E-03	4.92E-05	6.13E-07	4.83E-07	2.84E-07	1.09E-02
Pb-210	3.50E+00	6.40E-03	3.67E-02	4.11E-04	1.21E-04	4.91E-04	5.38E-04	1.36E-01
Pd-107	6.66E-05	3.83E-09	5.54E-07	4.22E-08	1.17E-07	2.32E-12	2.72E-11	1.03E-06
Pt-193	6.19E-05	3.53E-09	5.11E-07	3.92E-08	5.56E-08	0.00E+00	0.00E+00	3.35E-06
Pu-238	3.31E-01	6.66E-04	2.70E-03	5.71E-08	5.77E-07	1.77E-07	6.21E-08	1.54E-02
Pu-239	3.64E-01	8.00E-04	2.97E-03	6.28E-08	6.34E-07	2.01E-07	7.05E-08	1.69E-02
Pu-240	3.64E-01	7.99E-04	2.97E-03	6.28E-08	6.34E-07	2.01E-07	7.05E-08	1.69E-02
Pu-241	6.56E-03	8.80E-06	5.33E-05	1.13E-09	1.14E-08	3.08E-09	1.08E-09	3.05E-04
Pu-242	3.43E-01	7.55E-04	2.80E-03	5.93E-08	5.99E-07	1.90E-07	6.66E-08	1.60E-02
Pu-244	3.47E-01	7.62E-04	2.83E-03	5.99E-08	6.05E-07	1.91E-07	6.72E-08	1.61E-02
Ra-226	5.71E-01	1.17E-04	4.87E-03	1.54E-04	3.81E-05	2.07E-06	1.88E-05	3.54E-03

Table C-1: Biosphere Dose Conversion Factors for Ingestion Pathways for Select Radionuclides (Continued)

Radio-nuclide	Water Ingestion	Soil Ingestion	Fruit and Vegetable Ingestion	Meat Ingestion	Milk Ingestion	Poultry Ingestion	Egg Ingestion	Fish Ingestion
	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)
Ra-228	2.33E+00	3.93E-04	1.96E-02	6.27E-04	1.55E-04	8.36E-06	7.58E-05	1.44E-02
Se-79	5.88E-03	1.41E-05	1.09E-04	1.79E-05	4.91E-06	1.17E-05	1.68E-05	5.46E-02
Sm-147	8.06E-02	1.96E-04	8.42E-04	4.26E-06	4.39E-07	3.14E-08	5.52E-10	3.74E-03
Sm-151	1.70E-04	3.78E-07	1.74E-06	8.93E-09	9.23E-10	6.38E-11	1.12E-12	7.90E-06
Sn-126	8.70E-03	2.27E-05	8.27E-05	1.14E-04	1.56E-06	1.38E-06	1.52E-06	4.04E-02
Sr-90	5.00E-02	2.03E-06	4.75E-04	1.06E-05	1.16E-05	1.17E-07	1.79E-06	2.24E-04
Tc-99	1.13E-03	5.57E-09	2.48E-05	1.56E-06	4.64E-07	4.48E-09	3.93E-07	3.51E-05
Th-229	1.13E+00	2.66E-03	9.33E-03	4.10E-05	9.88E-07	1.28E-06	7.54E-07	1.05E-02
Th-230	3.18E-01	7.49E-04	2.62E-03	1.15E-05	2.78E-07	3.61E-07	2.12E-07	2.96E-03
Th-232	3.50E-01	8.24E-04	2.89E-03	1.27E-05	3.06E-07	3.97E-07	2.33E-07	3.25E-03
U-232	8.26E-01	1.26E-03	7.53E-03	5.21E-05	2.64E-04	1.01E-04	1.31E-04	1.23E-03
U-233	7.58E-02	1.28E-04	6.98E-04	4.79E-06	2.43E-05	9.59E-06	1.23E-05	1.13E-04
U-234	7.31E-02	1.23E-04	6.73E-04	4.62E-06	2.34E-05	9.25E-06	1.19E-05	1.09E-04
U-235	6.97E-02	1.17E-04	6.42E-04	4.41E-06	2.23E-05	8.82E-06	1.14E-05	1.04E-04
U-236	6.87E-02	1.16E-04	6.33E-04	4.34E-06	2.20E-05	8.69E-06	1.12E-05	1.02E-04
U-238	7.24E-02	1.22E-04	6.67E-04	4.58E-06	2.32E-05	9.16E-06	1.18E-05	1.08E-04
Zr-93	1.26E-03	2.96E-06	1.08E-05	2.40E-10	7.95E-10	1.43E-11	4.18E-11	4.29E-05

Table C-2: Biosphere Dose Conversion Factors for Exposure and Inhalation Pathways for Select Radionuclides

Radio-nuclide	Soil Exposure	Shower Exposure	Boating Exposure	Swimming Exposure	Shower Inhalation	Irrigation Inhalation	Dust Inhalation	Swimming Inhalation
	(mrem/yr)/(pCi/L)	(mrem/yr)/(pCi/L)	(mrem/yr)/(pCi/L)	(mrem/yr)/(pCi/L)	(mrem/yr)/(pCi/L)	(mrem/yr)/(pCi/L)	(mrem/yr)/(pCi/L)	(mrem/yr)/(pCi/L)
Ac-227	8.60E-04	5.82E-05	6.06E-06	8.25E-06	1.73E-04	9.47E-05	1.51E-04	5.96E-06
Ag-108m	1.71E-04	2.20E-04	2.29E-05	3.11E-05	7.45E-09	4.09E-09	3.12E-10	2.57E-10
Al-26	8.86E-03	3.90E-04	4.06E-05	5.53E-05	1.39E-08	7.65E-09	1.77E-08	4.82E-10
Am-241	2.30E-05	2.16E-06	2.25E-07	3.06E-07	1.04E-04	5.73E-05	1.27E-04	3.61E-06
Am-242m	3.45E-05	2.17E-06	2.26E-07	3.08E-07	1.02E-04	5.60E-05	1.20E-04	3.53E-06
Am-243	5.23E-04	2.88E-05	3.00E-06	4.08E-06	1.04E-04	5.70E-05	1.29E-04	3.59E-06
Bi-210m	7.77E-04	3.55E-05	3.70E-06	5.03E-06	5.78E-08	3.17E-08	7.19E-08	2.00E-09
C-14	2.35E-10	4.04E-09	4.21E-10	5.73E-10	2.32E-10	1.27E-10	9.73E-12	8.02E-12
Cf-249	9.66E-04	4.36E-05	4.54E-06	6.17E-06	1.90E-04	1.04E-04	2.30E-04	6.55E-06
Cf-251	2.83E-04	1.50E-05	1.56E-06	2.13E-06	1.93E-04	1.06E-04	2.37E-04	6.66E-06
Cl-36	4.97E-09	2.72E-07	2.84E-08	3.86E-08	4.37E-10	2.40E-10	1.83E-12	1.51E-11
Cm-243	2.50E-04	1.64E-05	1.71E-06	2.33E-06	7.62E-05	4.18E-05	7.21E-05	2.63E-06
Cm-244	7.52E-08	1.30E-08	1.35E-09	1.84E-09	6.27E-05	3.44E-05	5.14E-05	2.17E-06
Cm-245	2.20E-04	1.25E-05	1.30E-06	1.77E-06	1.06E-04	5.84E-05	1.32E-04	3.68E-06
Cm-246	1.17E-05	5.42E-07	5.65E-08	7.68E-08	1.06E-04	5.84E-05	1.32E-04	3.68E-06
Cm-247	1.01E-03	4.51E-05	4.70E-06	6.39E-06	9.75E-05	5.35E-05	1.21E-04	3.37E-06
Cm-248	4.23E-03	1.94E-04	2.03E-05	2.75E-05	3.91E-04	2.15E-04	4.86E-04	1.35E-05
Co-60	7.96E-04	3.61E-04	3.76E-05	5.12E-05	6.41E-09	3.52E-09	7.79E-10	2.22E-10
Cs-135	1.66E-09	3.32E-08	3.46E-09	4.71E-09	9.72E-10	5.33E-10	4.08E-11	3.36E-11
Cs-137	5.96E-05	7.73E-05	8.05E-06	1.10E-05	4.89E-09	2.68E-09	2.02E-10	1.69E-10
Eu-152	2.12E-03	1.64E-04	1.71E-05	2.33E-05	1.06E-07	5.79E-08	7.58E-08	3.65E-09

Table C-2: Biosphere Dose Conversion Factors for Exposure and Inhalation Pathways for Select Radionuclides (Continued)

Radio-nuclide	Soil Exposure	Shower Exposure	Boating Exposure	Swimming Exposure	Shower Inhalation	Irrigation Inhalation	Dust Inhalation	Swimming Inhalation
	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)
Eu-154	1.81E-03	1.75E-04	1.83E-05	2.48E-05	1.23E-07	6.72E-08	6.98E-08	4.23E-09
Eu-155	2.98E-05	6.83E-06	7.11E-07	9.67E-07	1.47E-08	8.06E-09	5.28E-09	5.08E-10
Gd-152	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.14E-05	1.17E-05	2.66E-05	7.39E-07
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.10E-12	3.90E-12	0.00E+00	2.45E-13
I-129	2.06E-08	9.36E-07	9.75E-08	1.33E-07	4.31E-08	2.37E-08	1.81E-10	1.49E-09
K-40	8.75E-06	2.35E-05	2.45E-06	3.33E-06	2.75E-09	1.51E-09	5.76E-11	9.49E-11
Mo-93	2.54E-07	5.59E-08	5.83E-09	7.92E-09	1.05E-09	5.76E-10	1.28E-09	3.63E-11
Nb-93m	1.60E-08	1.00E-08	1.04E-09	1.42E-09	2.96E-10	1.63E-10	1.27E-10	1.02E-11
Nb-94	2.38E-03	2.17E-04	2.26E-05	3.08E-05	7.07E-09	3.88E-09	4.20E-09	2.44E-10
Ni-59	1.15E-09	2.10E-09	2.19E-10	2.98E-10	2.15E-10	1.18E-10	6.31E-12	7.42E-12
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.29E-10	2.90E-10	1.55E-11	1.83E-11
Np-237	6.58E-06	3.12E-05	3.25E-06	4.42E-06	5.38E-05	2.95E-05	6.76E-07	1.86E-06
Pa-231	9.69E-07	4.45E-06	4.64E-07	6.31E-07	2.52E-04	1.38E-04	3.17E-06	8.71E-06
Pb-210	3.56E-06	5.71E-07	5.95E-08	8.09E-08	1.89E-06	1.04E-06	1.76E-06	6.53E-08
Pd-107	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.42E-11	1.88E-11	1.00E-12	1.18E-12
Pt-193	6.46E-11	9.20E-10	9.59E-11	1.30E-10	3.05E-11	1.67E-11	8.89E-13	1.05E-12
Pu-238	5.80E-08	1.09E-08	1.14E-09	1.55E-09	1.17E-04	6.42E-05	1.20E-04	4.04E-06
Pu-239	1.52E-07	1.19E-08	1.24E-09	1.69E-09	1.29E-04	7.07E-05	1.45E-04	4.45E-06
Pu-240	6.39E-08	1.07E-08	1.12E-09	1.52E-09	1.29E-04	7.07E-05	1.45E-04	4.45E-06
Pu-241	1.82E-09	1.92E-10	2.00E-11	2.72E-11	2.45E-06	1.34E-06	1.68E-06	8.46E-08
Pu-242	2.73E-07	2.00E-08	2.09E-09	2.84E-09	1.23E-04	6.72E-05	1.38E-04	4.23E-06
Pu-244	9.85E-04	4.84E-05	5.04E-06	6.85E-06	1.20E-04	6.60E-05	1.35E-04	4.15E-06

Table C-2: Biosphere Dose Conversion Factors for Exposure and Inhalation Pathways for Select Radionuclides (Continued)

Radio-nuclide	Soil Exposure	Shower Exposure	Boating Exposure	Swimming Exposure	Shower Inhalation	Irrigation Inhalation	Dust Inhalation	Swimming Inhalation
	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)	(mrem/yr)/ (pCi/L)
Ra-226	4.69E-04	2.51E-04	2.61E-05	3.55E-05	5.09E-07	2.79E-07	5.33E-08	1.76E-08
Ra-228	5.13E-04	3.41E-04	3.55E-05	4.83E-05	3.82E-05	2.10E-05	3.29E-06	1.32E-06
Se-79	7.93E-09	4.74E-09	4.94E-10	6.72E-10	1.79E-09	9.81E-10	2.19E-09	6.18E-11
Sm-147	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E-05	1.43E-05	3.23E-05	8.97E-07
Sm-151	4.18E-10	8.69E-11	9.05E-12	1.23E-11	1.05E-08	5.74E-09	1.19E-08	3.62E-10
Sn-126	6.66E-03	2.72E-04	2.84E-05	3.86E-05	1.44E-08	7.87E-09	1.91E-08	4.96E-10
Sr-90	4.15E-07	1.54E-06	1.60E-07	2.18E-07	3.02E-08	1.66E-08	6.28E-10	1.04E-09
Tc-99	1.41E-10	4.40E-08	4.59E-09	6.24E-09	3.85E-10	2.11E-10	9.70E-13	1.33E-11
Th-229	8.11E-04	4.10E-05	4.28E-06	5.81E-06	2.66E-04	1.46E-04	3.20E-04	9.20E-06
Th-230	6.66E-07	4.79E-08	4.99E-09	6.78E-09	1.11E-04	6.08E-05	1.33E-04	3.83E-06
Th-232	2.91E-07	2.52E-08	2.63E-09	3.57E-09	1.23E-04	6.72E-05	1.47E-04	4.23E-06
U-232	2.93E-03	2.18E-04	2.28E-05	3.09E-05	4.14E-05	2.27E-05	3.24E-05	1.43E-06
U-233	3.88E-07	3.29E-08	3.43E-09	4.66E-09	6.79E-07	3.72E-07	5.84E-07	2.35E-08
U-234	1.50E-07	1.96E-08	2.04E-09	2.77E-09	6.56E-07	3.60E-07	5.64E-07	2.27E-08
U-235	3.12E-04	2.26E-05	2.35E-06	3.20E-06	6.10E-07	3.35E-07	5.24E-07	2.11E-08
U-236	7.68E-08	1.21E-08	1.26E-09	1.72E-09	6.15E-07	3.38E-07	5.29E-07	2.13E-08
U-238	3.22E-03	2.08E-04	2.16E-05	2.94E-05	5.92E-07	3.25E-07	5.10E-07	2.05E-08
Zr-93	0.00E+00	9.46E-13	9.85E-14	1.34E-13	2.34E-08	1.28E-08	2.82E-08	8.09E-10

APPENDIX D

ASSESSMENT OF REVISED DOSE CALCULATION METHODOLOGY ON EXISTING PAS AND SAS

APPENDIX D. ASSESSMENT OF REVISED DOSE CALCULATION METHODOLOGY ON EXISTING PAS AND SAS

The dose calculation methodology introduced within this report is different than the methodology applied in the current (existing) Liquid Waste PAs. This appendix uses concentration data from the existing PAs to recalculate doses using this updated methodology in order to assess the impact of the recommended changes.

Note that the doses presented in this appendix do not represent actual projected dose, as would be developed for PAs or Special Analyses. Some modeling parameters (such as K_d values) are used in both concentration calculations and the dose calculations, such that the doses presented here may have internally inconsistent values. Additionally, coarse timesteps were used for this analysis; using smaller timesteps could yield different results, especially with respect to releases that occur quickly. Therefore the doses presented here are for comparison purposes only.

This appendix has four sections. Section D1 shows dose comparisons using FTF groundwater concentrations. Section D2 shows dose comparisons using HTF groundwater concentrations. Section D3 shows dose comparisons using SDF groundwater concentrations. Finally, Section D4 summarizes the dose comparisons and provides general conclusions.

D1. FTF Dose Comparison

At the time of the preparation of this report, the most current FTF contaminant concentrations were determined for the FTF Special Analysis for Tanks 5 and 6. [SRR-CWDA-2012-00106] This Special Analysis had two important modeling cases in it: the Evaluation Case (which was based on the Base Case from the FTF PA, only with updated inventory data) and the Composite Sensitivity Study (which incorporated a number of other parameter value updates). The following figures (Figure D1-1 and D1-2) applied the respective groundwater concentration values at the 100-meter boundary from these models to provide a total groundwater dose comparison. In general, the resulting doses were lower when using the revised dose calculation and the parameter values described within the body of this report.

Figure D1-1: 100-Meter MOP Dose Comparison Using Concentrations from the Tank 5 and 6 FTF Special Analysis, Evaluation Case (0-50,000 Years)

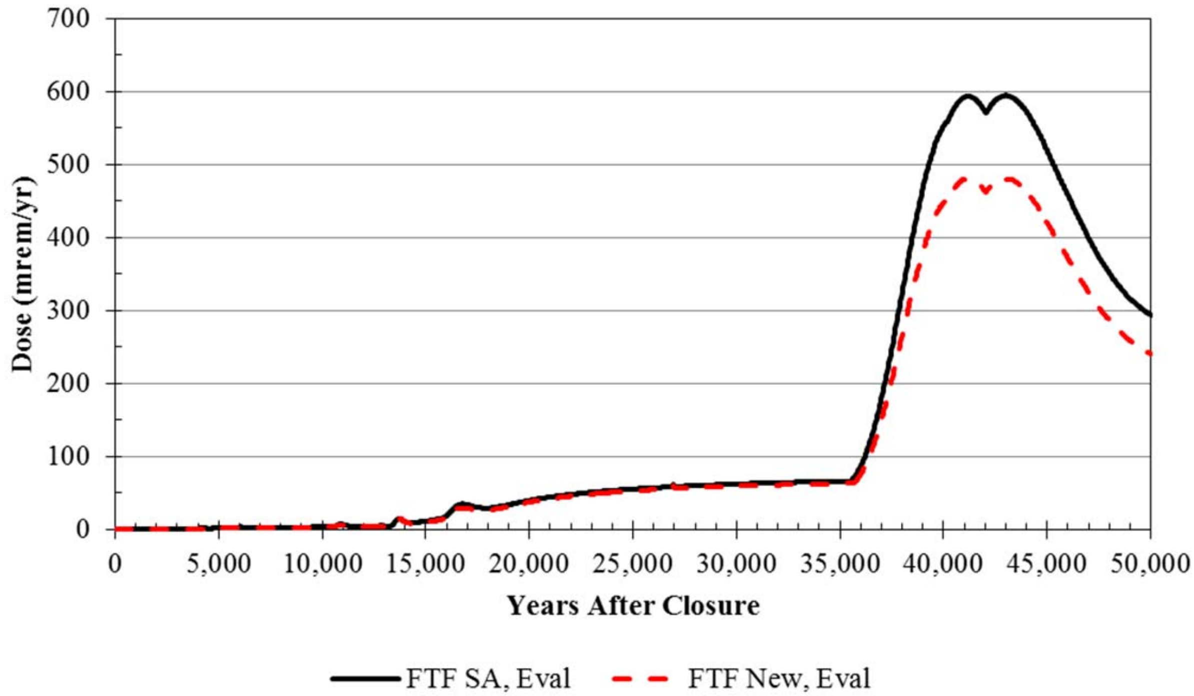
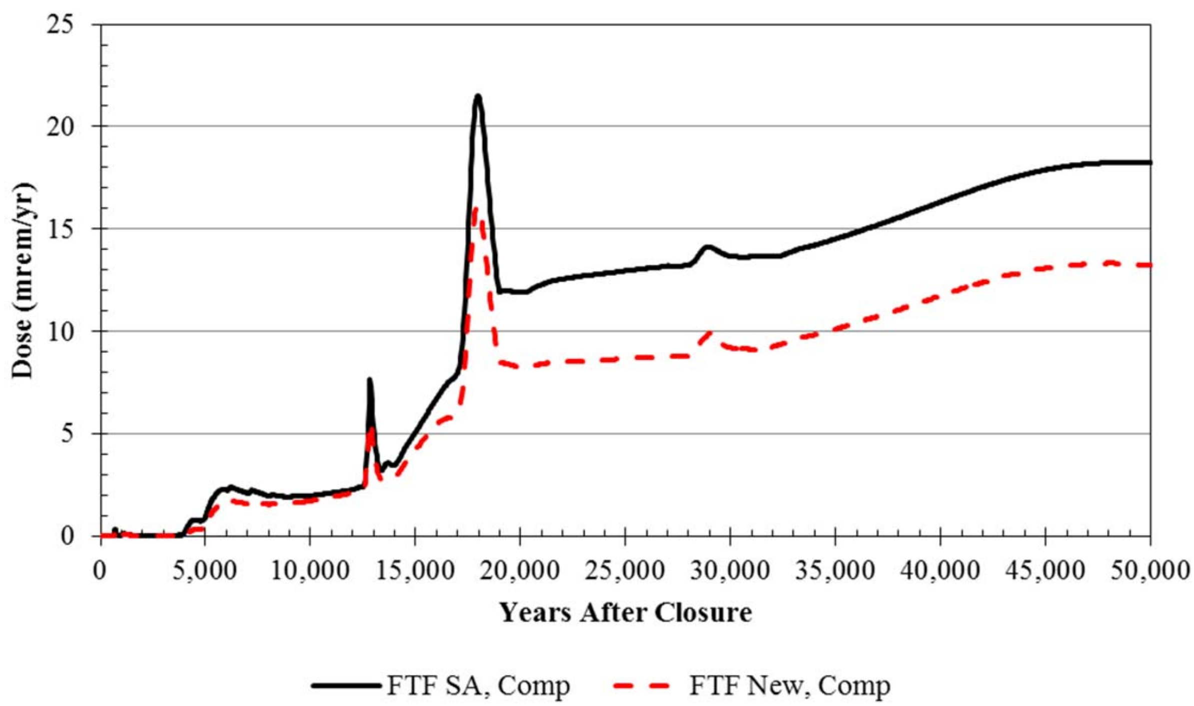


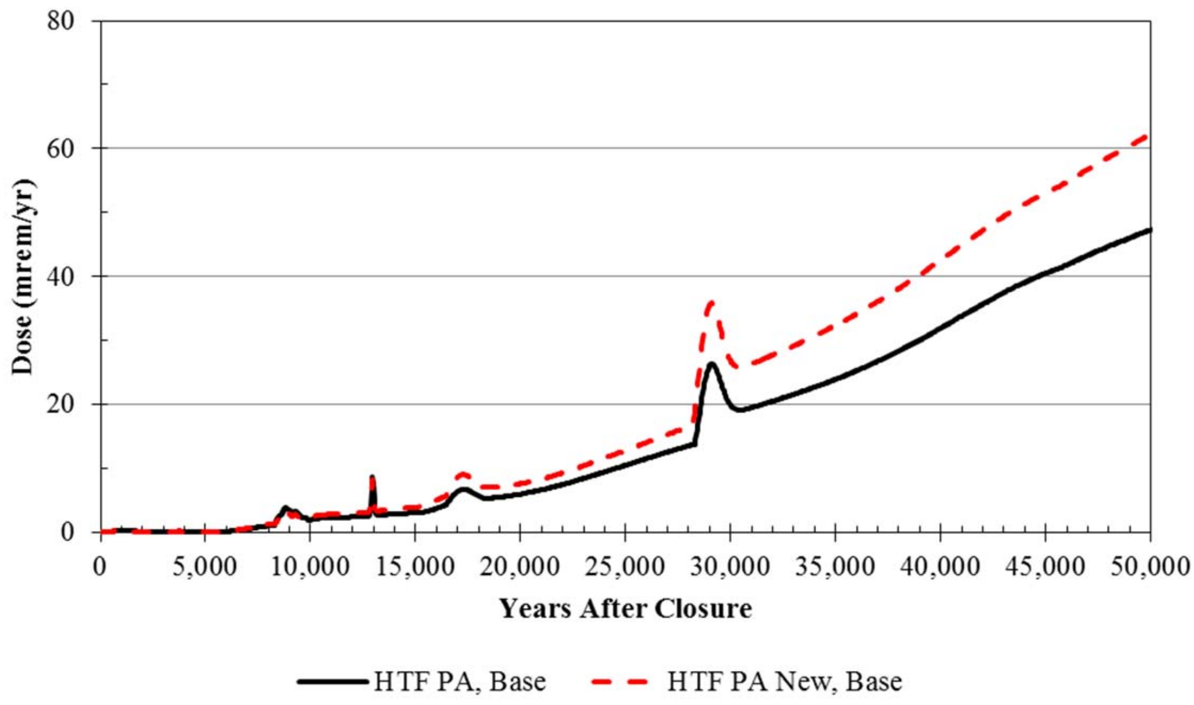
Figure D1-2: 100-Meter MOP Dose Comparison Using Concentrations from the Tank 5 and 6 FTF Special Analysis, Composite Sensitivity Study (0-50,000 Years)



D2. HTF Dose Comparison

At the time of the preparation of this report, the most current HTF contaminant concentrations were determined for the Revision 1 of the HTF PA. [SRR-CWDA-2010-00128] The following figure (Figure D2-1) applied the groundwater concentration values at the 100-meter boundary from the HTF PA Base Case model to provide a total dose comparison. In general, the resulting doses were lower within the first 10,000 years when using the revised dose calculation and the parameter values described within the body of this report. After 10,000 years, the revised dose results gradually increase to be approximately 10% to 15% higher than the doses in the HTF PA. This increase is driven by an increase to the Ra-226 dose conversion, particularly due to the increased water intake.

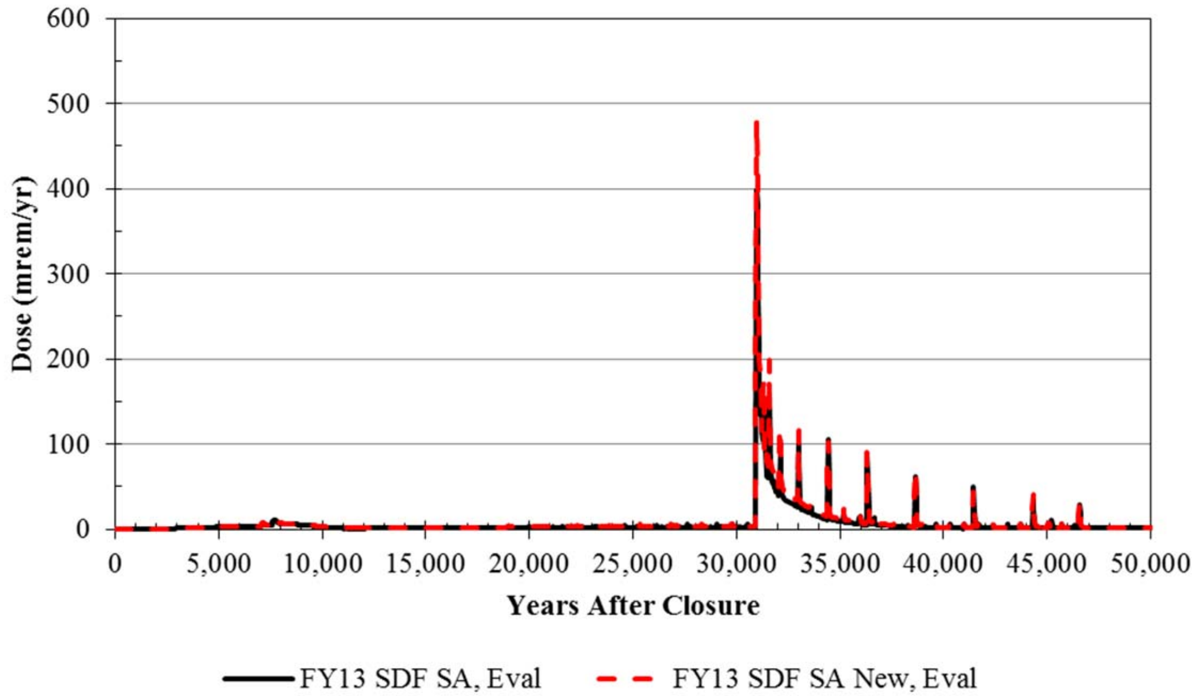
Figure D2-1: 100-Meter MOP Dose Comparison Using Concentrations from the HTF PA, Base Case (0-50,000 Years)



D3. SDF Dose Comparison

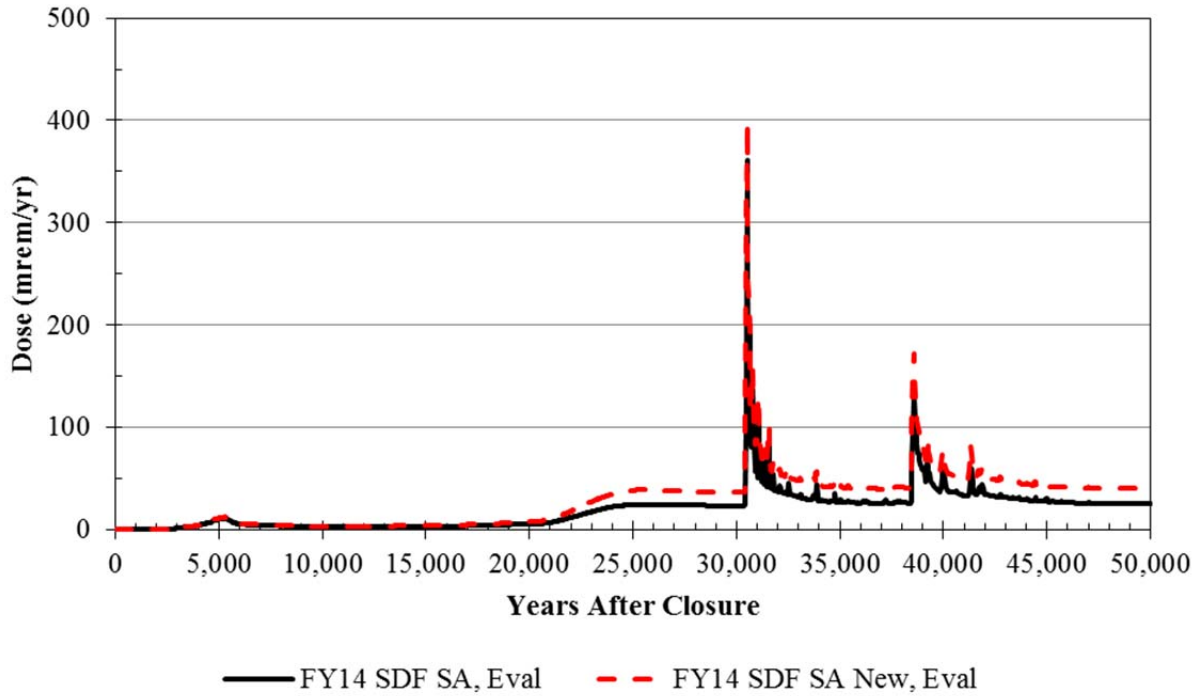
At the time of the preparation of this report, the most current SDF contaminant concentrations were determined for Revision 2 of the FY2013 SDF Special Analysis. [SRR-CWDA-2013-00062] The following figure (Figure D3-1) applied the groundwater concentration values at the 100-meter boundary from the Evaluation Case model in the FY2013 SDF Special Analysis to provide a total dose comparison. In general, the resulting doses were not significantly different when using the revised dose calculation and the parameter values described within the body of this report.

Figure D3-1: 100-Meter MOP Dose Comparison Using Concentrations from the FY2013 SDF Special Analysis, Evaluation Case (0-50,000 Years)



Finally, Figure D3-2 shown the results comparing the groundwater doses using the Evaluation Case concentrations from the FY2014 SDF Special Analysis. This Special Analysis is currently in internal DOE review and is subject to change.

Figure D3-2: 100-Meter MOP Dose Comparison Using Concentrations from the FY2014 SDF Special Analysis, Evaluation Case (0-50,000 Years)



D4. Summary of Dose Comparisons

Table D-1 shows the peak doses for the scenarios that were considered. As seen in the previous figures, none of the dose results significantly changed within the first 10,000 years of simulation. Beyond the first 10,000 years, FTF results were generally lower, HTF results were generally higher, and the SDF results were very similar through the application of this revised dose calculation. Again, note that results may vary based upon timesteps and other potential modeling parameters. The values shown here are intend for comparison purposes only and do not constitute specific "Base Case" results.

Table D-1: Peak Dose Comparisons

		Peak Dose (mrem/yr) to the 100-Meter MOP			
		Within 1,000 Years	Within 10,000 Years	Between 10,000 and 20,000 Years	Within 50,000 Years
FTF Tank 5/6 SA	SA Evaluation Case	0.41	3.3	39.7	594
	Revised Dose	0.35	2.9	37.4	480
	Composite Sensitivity Study	0.34	2.4	21.5	22
	Revised Dose	0.30	1.7	16.1	16.1
HTF PA, Rev. 1	PA Base Case	0.28	3.9	8.7	47
	Revised Dose	0.23	3.2	9.0	62
FY2013 SDF SA, Rev. 2	SA Evaluation Case	0.04	11.5	2.9	398
	Revised Dose	0.05	12.5	3.9	479
FY2014 SDF SA, Rev. 1	SA Evaluation Case	0.03	11.5	5.2	361
	Revised Dose	0.04	12.3	7.3	398