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

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Prepared by: Savannah River Remediation LLC
Closure and Waste Disposal Authority
Aiken, SC 29808

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APPROVALS

Preparer:

5/22/2013

Steve Hommel
C&WDA Assessments
Savannah River Remediation LLC

Date

Reviewer (per S4 ENG.51):

5/22/2013

Michael Schubert
C&WDA Assessments
Savannah River Remediation LLC

Date

Management Review:

5/23/2013

Kent Rosenberger
C&WDA Assessments
Savannah River Remediation LLC

Date

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ACRONYMS/ABBREVIATIONS

DCF	Dose Conversion Factor
DOE	U.S. Department of Energy
EDF	Effective Dose Factor
EPA	U.S. Environmental Protection Agency
FTF	F-Tank Farm
HTF	H-Tank Farm
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. The exposure scenarios used in this report are briefly described below.

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 in 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 to use in future dose calculations.

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 using the mean adult parameter definitions, consistent with guidance in DOE Guide 435.1-1, Section IV.P.(2).

> *"disposal based on the performance 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 likelihood of … scenarios may be considered in …establishing radionuclide concentrations, if adequate justification is provided."*

Where possible the critical group of exposed individuals is assumed to be an average (or mean) adult (i.e., values are selected based on average human behaviors). This concept is coupled with various conservative assumptions as discussed in the parameter decisions provided in Section 7. These assumptions provide a more conservative and defensible definition for the human receptors.

1.2 Exposure Scenarios

The MOP is an assumed "typical" future person. 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.). 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 3, below, provides the recommended dose methodology for calculating dose to the MOP at the 100-Meter Well. Section 4, below, 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 1-meter from the contaminated source. 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. 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.

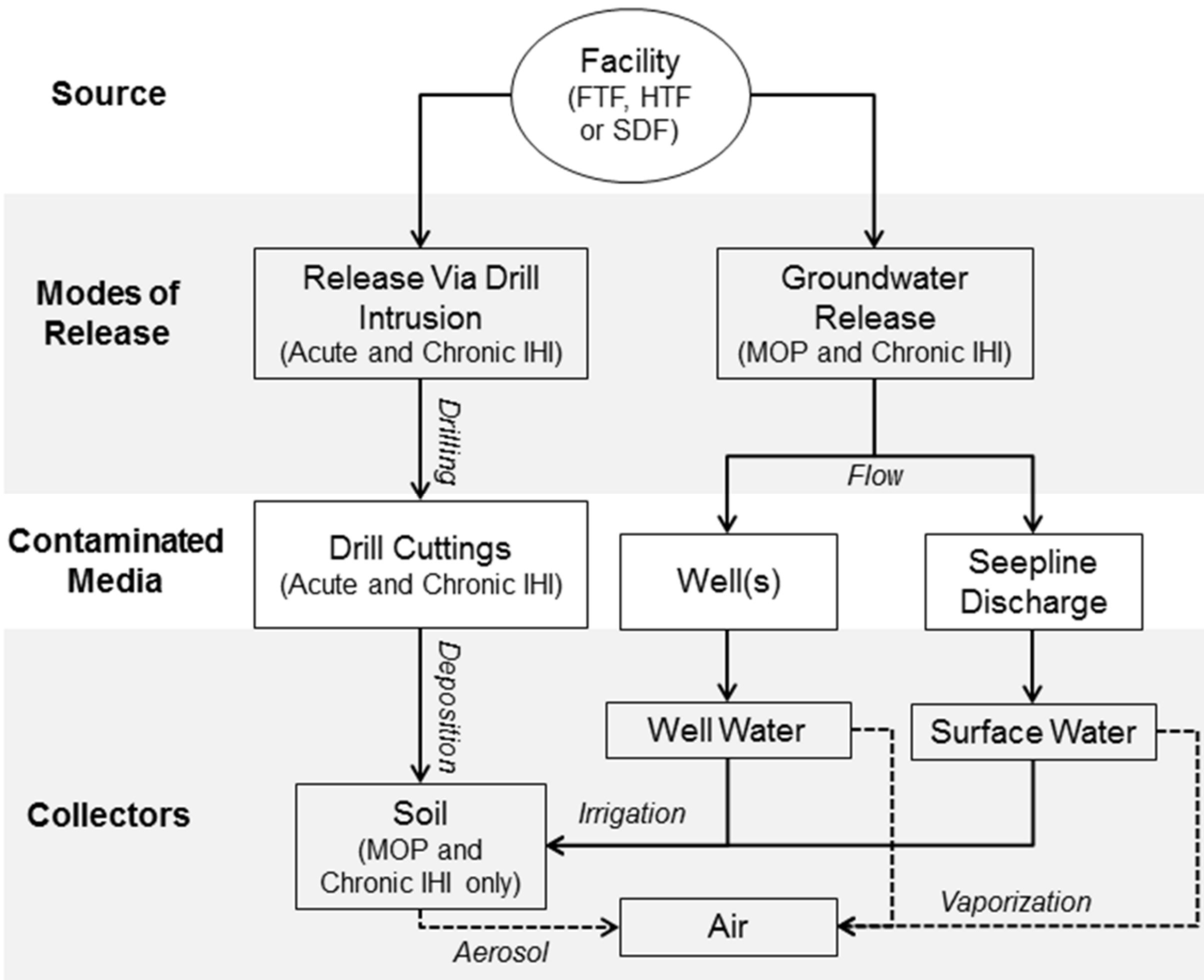
Section 5, below, provides the recommended dose methodology for calculating dose to the Acute IHI. Section 6, below, provides the recommended dose methodology for calculating dose to the Chronic IHI.

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.

1.3 Contaminant and Dose Process Overview

Figure 1-1 illustrates the process through which contaminants may be collected into the biosphere. 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



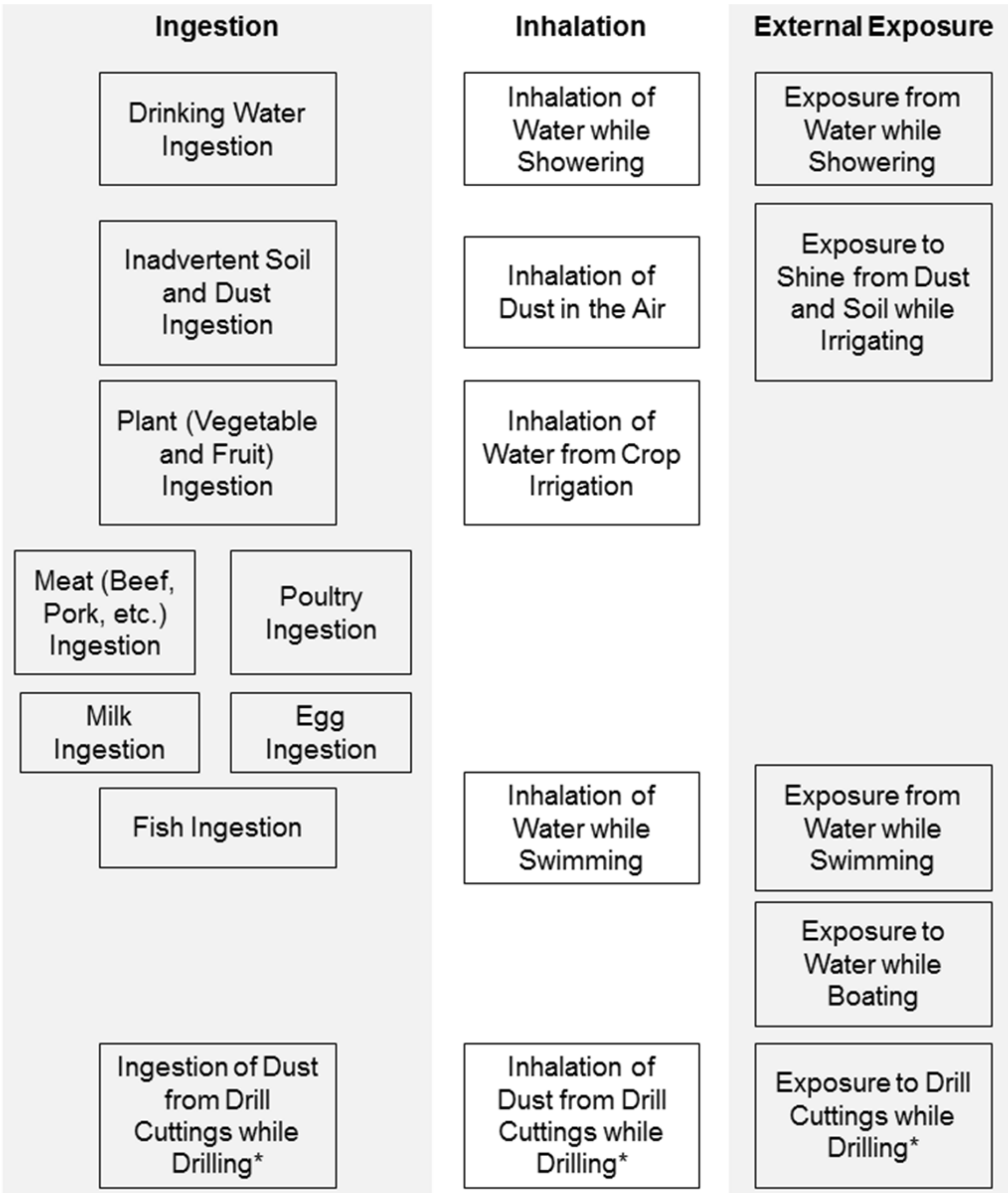
FTF = F-Tank Farm
HTF = H-Tank Farm
SDF = Saltstone Disposal Facility

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 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 to determining dose based on the exposure scenarios discussed in Section 1.1. 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) The vegetable ingestion pathway has been modified to include the ingestion of fruit and redefined as a produce ingestion pathway;

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

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

(4) 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 the IHI garden;

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

(6) 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]

(7) 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 6 are generally expected to increase dose results; however the new recommended parameter values (item 7) are generally expected to reduce the dose results. Appendix A incorporates all items (1 through 7, above), applying the dose methodology described within this report to the contaminant concentrations from current Liquid Waste PAs to assess the overall impact of all 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., 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 livestock meat (including 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:

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

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 ground water (L×mrem)/(pCi×yr), defined in Equation 3.1-2a, below

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

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

where:

EDF_{H2Oing}	=	effective dose factor for ingestion of contaminated ground water (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 ground water (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 exposure pathway from the ingestion of soil 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:

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

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 ground water (L×mrem)/(pCi×yr), defined in Equation 3.1-3a, below

The EDF for soil ingestion shall be calculated as:

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

where:

$EDF_{SOILing}$	=	effective dose factor for ingestion of soil contaminated by ground water (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:

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

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, this equation does not account for radiological ingrowth. As a modeling simplification, it is assumed that ingrowth is balanced by the removal of mass due to weathering. In other words, Equation 3.1-3b does not include any weathering decay terms because ingrowth is ignored (i.e., the effects of the two terms are expected to balance, such that ignoring both is a reasonable modeling assumption).

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:

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

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 ground water (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:

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

where:

$EDF_{PLANTing}$	=	effective dose factor for ingestion of plants contaminated by ground water (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:

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

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_L	=	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:

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

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:

$$ROOT = R_{StoV} \times SOIL \quad \text{(Eq. 3.1-4d)}$$

where:

$ROOT$ = 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 livestock exposure pathway assumes that 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. 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, livestock meat includes all meat that is not considered poultry or fish. This includes beef, pork, veal, and other game.

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

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

where:

$D_{MOP,100,MEATing}$	=	dose to the MOP at the 100-meter well (mrem/yr) due to ingestion of livestock meat (including 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 meat contaminated by ground water (L×mrem)/(pCi×yr), as defined in Equation 3.1-5a, below
$F_{local,MEAT}$	=	fraction of livestock meat (including beef, pork, veal, etc.) produced locally (unitless), Table 7.6-1

The EDF for meat ingestion shall be calculated as:

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

where:

$EDF_{MEATing}$	=	effective dose factor for ingestion of meat contaminated by ground water (L×mrem)/(pCi×yr)
$Q_{H2O,MEAT}$	=	consumption rate of water by meat producing livestock (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, below
$Q_{fod,MEAT}$	=	consumption rate of fodder by livestock (kg/yr), Table 7.2-2
$F_{fod,MEAT}$	=	fraction of livestock intake from field/pasture that is irrigated with water from the contaminated well (unitless), Table 7.2-3
TC_{MEAT}	=	transfer coefficient for livestock meat (including beef, pork, veal, etc.) (yr/kg), Table 7.3-2
U_{MEAT}	=	human consumption rate of livestock meat (including 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	=	livestock and 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)

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:

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

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 ground water (L×mrem)/(pCi×yr), as defined in Equation 3.1-6a, below
$F_{local,MILK}$	=	fraction of milk-producing livestock grown locally (unitless), Table 7.6-1

The EDF for milk ingestion shall be calculated as:

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

where:

$EDF_{MILKing}$	=	effective dose factor for ingestion of milk contaminated by ground water (L×mrem)/(pCi×yr)
$Q_{H2O,MILK}$	=	consumption rate of water by milk producing livestock (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
$Q_{fod,MILK}$	=	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 (L/yr), Table 7.2-1
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 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 ground water (L×mrem)/(pCi×yr), as defined in Equation 3.1-7a, below
$F_{local,POULTRY}$	=	fraction of poultry produced locally (unitless), Table 7.6-1

The EDF for poultry ingestion shall be calculated as:

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

where:

$EDF_{POULTRYing}$	=	effective dose factor for ingestion of poultry contaminated by ground water (L×mrem)/(pCi×yr)
$Q_{H2O,POULTRY}$	=	consumption rate of water by poultry (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
$Q_{fod,POULTRY}$	=	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)

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

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

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 ground water (L×mrem)/(pCi×yr), as defined in Equation 3.1-8a, below

$F_{local,EGG}$ = fraction of eggs produced locally (unitless), Table 7.6-1

The EDF for egg ingestion shall be calculated as:

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

where:

EDF_{EGGing} = effective dose factor for ingestion of eggs contaminated by ground water (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 exposure route assumes fish are caught from a stream contaminated from the aquifer with the 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:

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

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

The EDF for fish ingestion shall be calculated as:

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

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

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:

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

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:

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

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:

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

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:

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

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 stream contaminated from the aquifer. The dose from swimming exposure shall be calculated according to Equation 3.2-4:

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

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:

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

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 stream contaminated from the aquifer. The dose from boating exposure shall be calculated according to Equation 3.2-5:

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

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:

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

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:

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

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:

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

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 7.5-1

$SOIL$ = 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 a stream contaminated from the aquifer 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 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:

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

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:

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

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 livestock meat (including 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 ground water (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 ground water (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 ground water (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 livestock exposure pathway assumes that livestock 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. 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, livestock meat includes all meat that is not considered poultry or fish. This includes beef, pork, veal, and other game.

Following the livestock consumption of the contaminated water and fodder, the MOP receptor consumes the contaminated meat. The dose from ingesting contaminated livestock 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 livestock meat (including 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 meat contaminated by ground water (L×mrem)/(pCi×yr), as defined in Equation 3.1-5a (see Section 3.1.4)
$F_{local,MEAT}$	=	fraction of livestock meat (including beef, pork, veal, etc.) produced 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 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 ground water (L×mrem)/(pCi×yr), as defined in Equation 3.1-6a (see Section 3.1.5)
$F_{local,MILK}$	=	fraction of milk-producing livestock grown locally (unitless), Table 7.6-1

4.1.6 Ingestion of Poultry (MOP at the SL)

The poultry and egg exposure 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 ground water (L×mrem)/(pCi×yr), as defined in Equation 3.1-7a (see Section 3.1.6)
$F_{local,POULTRY}$	=	fraction of poultry produced 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 ground water (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 exposure route assumes fish are caught from a stream contaminated from the aquifer with the 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:

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

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 stream contaminated from the aquifer. 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 activities at a stream contaminated from the aquifer. 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:

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

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:

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

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:

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

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:

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

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 a stream contaminated from the aquifer 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 7.5-1
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:

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

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:

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

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 livestock meat (including 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 ground water (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 ground water (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:

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

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:

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

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 ground water $D_{IHIC,H2OPLANTing}$ 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 ground water (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:

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

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 livestock exposure pathway assumes that livestock 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, 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, livestock meat includes all meat that is not considered poultry or fish. This includes beef, pork, veal, and other game.

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

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

where:

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

$D_{IHIC,H2OMEATing}$ = dose to the chronic IHI (mrem/yr) due to ingestion of meat 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 that has been contaminated by drill cuttings
$F_{IHI,local,MEAT}$	=	fraction of consumed meat grown locally (unitless), Table 7.6-1

The dose from ingestion of meat contaminated by ground water $D_{IHIC,H2OMEATing}$ is calculated using the following formula:

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

where:

$D_{IHIC,H2OMEATing}$	=	dose to the chronic IHI (mrem/yr) due to ingestion of meat 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 meat contaminated by ground water (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:

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

where:

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

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

where:

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

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

$ROOT$ = radionuclide uptake through produce roots ((m^2×yr)/kg), as defined in Equation 3.1-4d (see Section 3.1.3)

$F_{fodIHI,MEAT}$ = fraction of 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 livestock meat (including beef, pork, veal, etc.) (yr/kg), Table 7.3-2

U_{MEAT} = human consumption rate of livestock meat (including 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:

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

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 grown locally (unitless), Table 7.6-1

The dose from ingestion of milk contaminated by ground water $D_{IHIC,H2OMILKing}$ 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 ground water (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:

$$EDF_{IHI,MILKing} = \left(\left(Q_{fod,MILK} \times ROOT \times F_{fod,MILK}\right) \times \left(PR + I_{RF} - ER\right)\right) \times TC_{MILK} \times U_{MILK} \times DCF_{ing} \quad \text{(Eq. 6.1-6c)}$$

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

$ROOT$ = radionuclide uptake through produce roots ((m^2×yr)/kg), as defined in

Equation 3.1-4d (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
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 exposure 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:

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

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 grown locally (unitless), Table 7.6-1

The dose from ingestion of poultry contaminated by ground water $D_{IHIC,H2OPOULTRYing}$ 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 ground water (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:

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

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

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

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 grown locally (unitless), Table 7.6-1

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

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

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 ground water (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:

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

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:

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

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

$ROOT$	=	radionuclide uptake through produce roots ((m^2×yr)/kg), as defined in Equation 3.1-4d (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 exposure route assumes fish are caught from a stream contaminated from the aquifer with the 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 ground water $D_{IHIC,H2OSOIL\exp}$ is calculated using the following formula:

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

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:

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

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:

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

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 stream contaminated from the aquifer. 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 at a stream contaminated from the aquifer. 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:

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

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 ground water $D_{IHIC,H2ODUSTinh}$ is calculated using the following formula:

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

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 7.5-1

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:

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

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 a stream contaminated from the aquifer 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).

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 adult, as consistent with guidance in DOE Guide 435.1-1, Section IV.P.(2); in accordance with this assumption, the values shown in Table 7.1-1 apply internal DCFs for an adult rather than that of 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	1.43E-04	2.73E-02	3.21E-08	1.47E-07
Ac-227	1.19E-03	2.69E-01	1.61E-10	9.63E-10
Ac-227 [a]	1.61E-03	3.28E-01	1.21E-06	4.85E-06
Ac-228	1.40E-06	4.40E-05	2.72E-06	1.01E-05
Ag-108m	8.70E-06	2.77E-05	5.03E-06	1.83E-05
Al-26	1.29E-05	7.22E-05	8.58E-06	3.25E-05
Am-241	7.55E-04	1.54E-01	2.32E-08	1.80E-07
Am-242	1.11E-06	6.40E-05	2.80E-08	1.48E-07
Am-242m	7.03E-04	1.36E-01	6.59E-10	5.29E-09
Am-242m [a]	7.40E-04	1.52E-01	3.61E-08	1.81E-07
Am-243	7.51E-04	1.52E-01	8.03E-08	5.07E-07
Am-243 [a]	7.54E-04	1.52E-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	5.70E-06	1.18E-05	1.07E-06	4.16E-06
Ba-137m	0.00E+00	0.00E+00	1.88E-06	6.81E-06
Bi-210	4.85E-06	3.45E-04	3.35E-09	3.48E-08
Bi-210m [a]	5.55E-05	1.27E-02	7.62E-07	2.91E-06
Bi-211	5.55E-05	1.27E-02	7.70E-07	2.96E-06
Bi-212	0.00E+00	0.00E+00	3.37E-07	1.26E-06

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-213	7.33E-07	1.10E-04	3.93E-07	1.47E-06
Bi-214	4.14E-07	5.40E-05	4.76E-06	1.80E-05
Bk-249	3.67E-06	6.14E-04	3.85E-12	6.33E-11
C-14	2.15E-06	7.51E-06	6.91E-12	3.37E-10
Ca-41	8.40E-07	4.11E-07	0.00E+00	0.00E+00
Cd-113m	8.66E-05	1.97E-04	5.46E-10	1.24E-08
Ce-144	1.94E-05	1.33E-04	3.91E-08	1.88E-07
Cf-249	1.30E-03	2.59E-01	9.80E-07	3.63E-06
Cf-250	5.96E-04	1.25E-01	3.14E-08	1.21E-07
Cf-251	1.32E-03	2.63E-01	2.83E-07	1.25E-06
Cf-252	3.35E-04	7.29E-02	1.46E-06	5.62E-06
Cl-36	3.43E-06	2.70E-05	1.46E-09	2.27E-08
Cm-242	4.33E-05	1.92E-02	7.93E-11	1.06E-09
Cm-243	5.55E-04	1.17E-01	3.25E-07	1.37E-06
Cm-244	4.55E-04	9.84E-02	1.13E-10	1.08E-09
Cm-245	7.70E-04	1.57E-01	2.18E-07	1.04E-06
Cm-246	7.66E-04	1.57E-01	1.16E-08	4.52E-08
Cm-247	7.07E-04	1.43E-01	9.55E-07	3.51E-06
Cm-247 [a]	7.07E-04	1.43E-01	9.99E-07	3.76E-06
Cm-248	2.87E-03	5.51E-01	4.19E-06	1.62E-05
Co-60	1.27E-05	3.77E-05	8.07E-06	3.01E-05
Cs-134	7.14E-05	3.40E-05	4.92E-06	1.79E-05
Cs-135	9.81E-06	1.44E-05	4.88E-11	2.77E-09
Cs-137	5.03E-05	3.60E-05	5.34E-10	1.23E-08
Cs-137 [a]	5.03E-05	3.60E-05	1.78E-06	6.44E-06
Eu-152	4.96E-06	1.56E-04	3.63E-06	1.37E-05
Eu-154	7.29E-06	1.90E-04	3.92E-06	1.46E-05
Eu-155	1.23E-06	2.59E-05	1.02E-07	5.69E-07
Fr-221	0.00E+00	0.00E+00	8.01E-08	3.21E-07
Fr-223	8.81E-06	3.89E-05	1.04E-07	5.31E-07
Gd-152	1.52E-04	2.95E-02	0.00E+00	0.00E+00
H-3	7.07E-08	1.67E-07	0.00E+00	0.00E+00
I-129	4.00E-04	5.70E-05	6.06E-09	7.80E-08
K-40	2.28E-05	5.14E-05	5.14E-07	1.96E-06
Kr-85	0.00E+00	0.00E+00	7.79E-09	4.38E-08
Lu-174	1.05E-06	1.67E-05	2.55E-07	1.15E-06
Mo-93	1.07E-05	2.07E-06	2.56E-10	4.66E-09
Mo-93m	4.44E-07	6.29E-07	7.39E-06	2.76E-05
Na-22	1.17E-05	3.66E-05	6.97E-06	2.57E-05
Nb-93m	4.77E-07	1.98E-06	4.57E-11	8.33E-10
Nb-94	6.40E-06	3.96E-05	4.95E-06	1.81E-05
Ni-59	2.31E-07	4.85E-07	4.83E-11	1.75E-10
Ni-63	5.74E-07	1.80E-06	0.00E+00	0.00E+00
Np-237	3.96E-04	8.40E-02	4.18E-08	2.25E-07

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}
Np-237 [a]	3.99E-04	8.40E-02	6.44E-07	2.60E-06
Np-238	3.31E-06	7.88E-06	1.86E-06	6.87E-06
Np-239	3.01E-06	3.52E-06	4.39E-07	1.89E-06
Np-240	2.68E-07	2.56E-07	3.22E-06	1.20E-05
Np-240m	0.00E+00	0.00E+00	1.01E-06	3.74E-06
Pa-231	1.77E-03	3.46E-01	9.49E-08	3.71E-07
Pa-233	3.57E-06	1.32E-05	6.02E-07	2.37E-06
Pa-234	1.55E-06	1.18E-06	4.53E-06	1.69E-05
Pa-234m	0.00E+00	0.00E+00	6.96E-08	2.86E-07
Pb-209	2.10E-07	2.09E-07	4.64E-10	1.31E-08
Pb-210	2.58E-03	4.11E-03	1.31E-09	1.27E-08
Pb-210 [a]	7.06E-03	1.66E-02	4.69E-09	4.76E-08
Pb-211	6.59E-07	4.11E-05	2.06E-07	7.80E-07
Pb-212	2.22E-05	6.36E-04	3.78E-07	1.56E-06
Pb-214	5.14E-07	5.03E-05	7.34E-07	2.81E-06
Pd-107	1.42E-07	3.31E-07	0.00E+00	0.00E+00
Pm-147	9.66E-07	1.83E-05	2.69E-11	1.13E-09
Po-210	4.48E-03	1.21E-02	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	1.87E-07	6.48E-08	1.32E-07	5.20E-07
Pt-193	1.32E-07	3.50E-07	2.73E-12	7.67E-11
Pu-238	8.44E-04	1.71E-01	6.94E-11	9.12E-10
Pu-239	9.29E-04	1.86E-01	1.67E-10	9.94E-10
Pu-240	9.29E-04	1.86E-01	7.01E-11	8.94E-10
Pu-241	1.75E-05	3.33E-03	3.26E-12	1.60E-11
Pu-242	8.84E-04	1.76E-01	2.99E-10	1.67E-09
Pu-243	3.16E-07	3.07E-07	4.40E-08	2.43E-07
Pu-244	8.81E-04	1.73E-01	6.33E-08	2.44E-07
Pu-244 [a]	8.85E-04	1.73E-01	1.08E-06	4.03E-06
Ra-223	3.81E-04	2.75E-02	3.47E-07	1.48E-06
Ra-224	2.39E-04	1.10E-02	2.97E-08	1.15E-07
Ra-225	3.69E-04	2.32E-02	5.57E-09	6.34E-08
Ra-226	1.04E-03	1.28E-02	1.94E-08	7.99E-08
Ra-226 [a]	1.04E-03	1.29E-02	5.52E-06	2.09E-05
Ra-228	2.58E-03	9.77E-03	4.11E-11	7.92E-10
Ra-228 [a]	3.11E-03	1.40E-01	7.34E-06	2.84E-05
Rb-87	5.66E-06	1.80E-05	8.41E-11	4.55E-09
Re-188	5.03E-06	1.99E-06	1.89E-07	7.71E-07

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}
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
Rn-222	0.00E+00	0.00E+00	1.21E-09	4.39E-09
Ru-106	2.60E-05	1.03E-04	0.00E+00	0.00E+00
S-35	4.85E-07	5.29E-06	7.62E-12	3.97E-10
Sb-125	4.26E-06	1.79E-05	1.31E-06	4.81E-06
Sb-126	9.92E-06	1.14E-05	8.69E-06	3.16E-05
Sb-126m	1.41E-07	7.14E-08	4.87E-06	1.77E-05
Sc-46	5.44E-06	2.21E-05	6.42E-06	2.37E-05
Se-79	1.01E-05	9.10E-06	7.97E-12	3.95E-10
Sm-147	1.83E-04	3.56E-02	0.00E+00	0.00E+00
Sm-151	3.66E-07	1.48E-05	4.53E-13	7.24E-12
Sn-121	8.51E-07	8.47E-07	1.10E-10	5.09E-09
Sn-121m	1.43E-06	1.65E-05	9.04E-10	1.31E-08
Sn-126	1.78E-05	1.05E-04	8.15E-08	4.78E-07
Sn-126 [a]	1.93E-05	1.07E-04	6.17E-06	2.27E-05
Sr-90	1.02E-04	1.31E-04	3.99E-10	1.27E-08
Sr-90 [a]	1.12E-04	1.36E-04	2.46E-08	1.28E-07
Tc-99	2.38E-06	1.49E-05	6.88E-11	3.67E-09
Te-125m	3.22E-06	1.24E-05	6.95E-09	9.08E-08
Th-227	3.37E-05	3.11E-02	3.36E-07	1.34E-06
Th-228	2.66E-04	1.18E-01	4.45E-09	2.15E-08
Th-229	1.85E-03	4.00E-01	1.77E-07	8.64E-07
Th-229 [a]	2.36E-03	4.50E-01	8.31E-07	3.42E-06
Th-230	7.92E-04	1.58E-01	6.82E-10	3.99E-09
Th-231	1.24E-06	1.14E-06	2.03E-08	1.19E-07
Th-232	8.55E-04	1.68E-01	2.98E-10	2.10E-09
Th-234	1.25E-05	2.46E-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	1.24E-03	2.89E-02	4.46E-10	2.84E-09
U-232 [a]	1.76E-03	1.59E-01	4.62E-06	1.82E-05
U-233	1.89E-04	1.31E-02	5.56E-10	2.74E-09
U-234	1.83E-04	1.29E-02	2.15E-10	1.63E-09
U-235	1.73E-04	1.14E-02	4.26E-07	1.76E-06
U-235 [a]	1.74E-04	1.14E-02	4.47E-07	1.88E-06
U-236	1.72E-04	1.18E-02	1.10E-10	1.01E-09
U-238	1.65E-04	1.06E-02	1.01E-10	8.55E-10
U-238 [a]	1.79E-04	1.06E-02	4.61E-06	1.73E-05
U-240	4.03E-06	1.93E-06	9.25E-09	5.02E-08
W-181	3.20E-07	6.66E-07	4.00E-08	3.07E-07
W-185	1.64E-06	1.10E-05	2.29E-10	6.62E-09

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}
W-188	7.73E-06	4.11E-05	5.29E-09	2.43E-08
Y-90	9.92E-06	5.14E-06	2.42E-08	1.15E-07
Zr-93	3.96E-06	3.63E-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.

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

Original Parent Radionuclide	Daughters Assumed at Equilibrium	Original Parent Radionuclide	Daughters Assumed at Equilibrium	Original Parent Radionuclide	Daughters Assumed at Equilibrium
Ac-227	Th-227	Ra-226	Rn-222	Th-229	Ra-225
	Fr-223		Po-218		Ac-225
	Ra-223		Pb-214		Fr-221
	Rn-219		At-218		At-217
	Po-215		Bi-214		Bi-213
	Pb-211		Po-214		Po-213
	Bi-211	Ra-228	Ac-228		Tl-209
	Tl-207		Th-228		Pb-209
	Po-211		Ra-224	U-232	Th-228
Am-242m	Am-242		Rn-220		Ra-224
	Np-238		Po-216		Rn-220
	Cm-242		Pb-212		Po-216
Am-243	Np-239		Bi-212		Pb-212
Bi-210m	Tl-206		Po-212		Bi-212
Cm-247	Pu-243		Tl-208		Po-212
Cs-137	Ba-137m	Sn-126	Sb-126m		Tl-208
Np-237	Pa-233		Sb-126	U-235	Th-231
Pb-210	Bi-210	Sr-90	Y-90	U-238	Th-234
	Po-210				Pa-234m
Pu-244	U-240				Pa-234
	Np-240m				

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, followed by a description of how each parameter was determined. These human uptake parameters were all developed based on the EPA's *Exposure Factors Handbook*, as described below. [EPA-600-R-090-052F] Note that these parameters assume that the MOP and IHI receptors are adults.

Table 7.2-1: Human Uptake Parameters

Parameter	Symbol in Equations	Unit	Value [a]	Probabilistic Value				
				Distribution	Mean / Mode	SD	Min	Max
rate of water consumption	U_{H2O}	L/yr	377	Log-Normal	377	300	48	1613
rate of soil and dust consumption	U_{SOIL}	kg/yr	1.83E-02	Triangular	1.83E-02	N/A	9.13E-03	3.65E-2
rate of produce consumption	U_P	kg/yr	200	Log-Normal	200	260	17.8	604
rate of meat consumption	U_{MEAT}	kg/yr	61.4	Log-Normal	61.4	50	9.2	147
rate of milk consumption	U_{MILK}	L/yr[b]	83.7	Log-Normal	83.7	165	3.8	317
rate of poultry consumption	$U_{POULTRY}$	kg/yr	10.6	Log-Normal	10.6	9	1.6	25.4
rate of egg consumption	U_{EGG}	kg/yr	7.3	Log-Normal	7.3	16	0.33	27.7
rate of fish consumption	U_{FISH}	kg/yr	5.62	Log-Normal, Geometric	5.62	2.3	1.4	32.4
human breathing rate	U_{air}	m^3/yr	5844	Normal	5844	950	2162	9624

a This is the recommended value, for use in deterministic modeling.
b This value is based on an assumed milk density of 1.03 kg/L^3. [WSRC-STI-2007-00004, Revision 4]
SD = standard deviation
N/A = Not Applicable

7.2.1.1 Water Consumption Rate

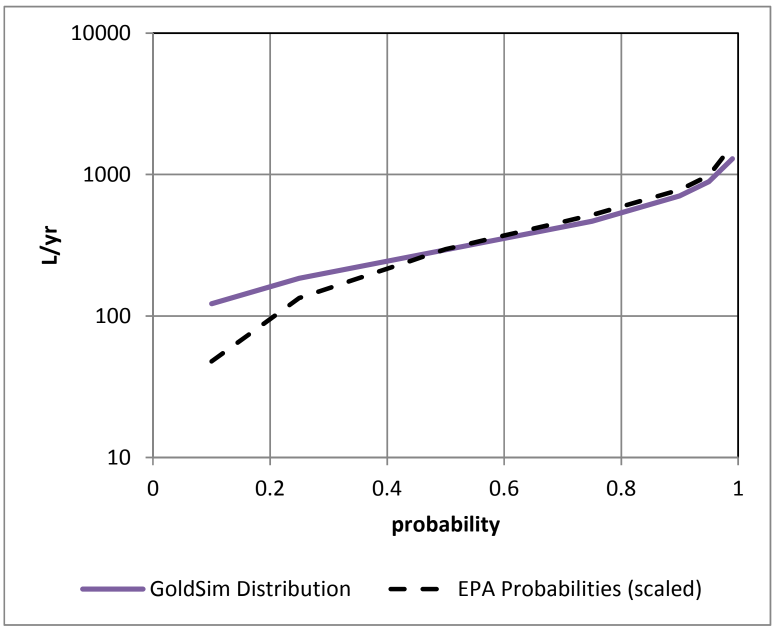
Table 3-1 of the EPA's *Exposure Factors Handbook* provides a number of recommended values for water consumption rates. [EPA-600-R-090-052F] For Liquid Waste PAs, it is assumed that the receptors (MOP and IHI) are representative of the general adult population. Therefore, the "All ages" values in the EPA table best represent the receptors. The EPA table provides two values for the "All ages" water ingestion rates: one for per capita and one for consumers only. For conservatism, Liquid Waste PAs should use the higher of the two values. In this case, the value of 1,033 mL/day (or approximately 377 L/yr) was selected as the recommended value to use in deterministic modeling.

The probabilistic distribution for water consumption was developed based on Table 3-15 of the EPA's *Exposure Factors Handbook*. [EPA-600-R-090-052F] This EPA table shows

human drinking rate distributions based on a number of age groups. Again, the data for the "All ages" group was selected, however the mean value shown in this table (1,000 mL/day) was less than the deterministic value that was selected (1,033 mL/day), so the distribution data was scaled up (i.e., increased by about 3 %) to maintain internal consistency. The distribution data was then plotted on a curve.

Next, a GoldSim stochastic element was created that closely reflected the values from the EPA table. Figure 7.2-1 shows the EPA distribution and the GoldSim distribution that was developed for use in dose modeling. Details for the GoldSim distribution are provided in Table 7.2-1.

Figure 7.2-1: Developed Distribution Curve for Water Consumption Rate



7.2.1.2 Soil and Dust Consumption Rate

Table 5-1 of the EPA's *Exposure Factors Handbook* provides a number of recommended values for soil and dust consumption rates. [EPA-600-R-090-052F] For Liquid Waste PAs, it is assumed that the receptors (MOP and IHI) are representative of the general adult population. Therefore, the adult value for the "General Population Central Tendency" in the EPA table best represents the receptors. In this case, the value of 50 mg/day was selected as the recommended value to use in deterministic modeling.

Unlike the data reported for water consumption distributions (as discussed above), the EPA's *Exposure Factors Handbook* provides very little insight to adult 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., 25 mg/day) and a maximum value of twice the deterministic rate (i.e., 100 mg/day).

The values were then converted from mg/day by multiplying the consumption rate by 1.0E-06 kg/mg to get kg/day, then multiplying the product by 365.25 day/yr. For example, the recommended deterministic value of 50 mg/day × 1.0E-06 kg/mg × 365.25 day/yr = 1.83E-02 kg/yr.

7.2.1.3 Produce Consumption Rate

Tables 9-7 and 9-8 of the EPA's *Exposure Factors Handbook* provide a number of mean consumption rates for fruits and vegetables based on surveys taken over various periods of time. [EPA-600-R-090-052F] As with human water consumption, the "All Ages" values were selected as representative of the dose receptors (MOP and IHI) and the "consumer-only" values (rather than the per capita values) were selected for conservatism. Based on this approach, the sum of the fruit intake and the vegetable intake for each survey period was determined as follows:

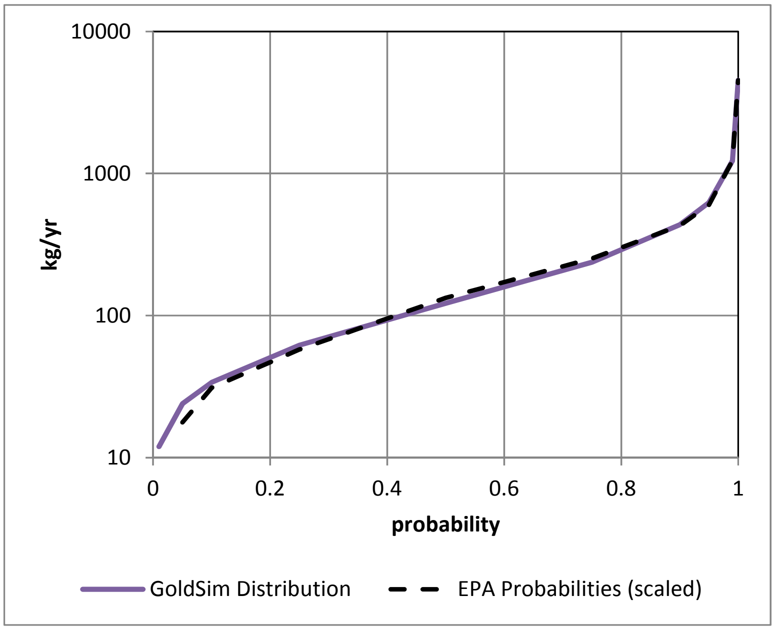
- Produce (fruit + vegetable) intake for the 1977-1978 survey was 498 g/day
- Produce (fruit + vegetable) intake for the 1987-1988 survey was 496 g/day
- Produce (fruit + vegetable) intake for the 1994 survey was 539 g/day
- Produce (fruit + vegetable) intake for the 1995 survey was 547 g/day

The 1995 survey shows the highest intake rate (547 g/day or approximately 200 kg/yr). Therefore, this value was conservatively selected as the recommended value for the total produce consumption rate to use in deterministic modeling.

The probabilistic distribution for produce consumption was developed based on Table 9-3 of the EPA's *Exposure Factors Handbook*. [EPA-600-R-090-052F] This EPA table shows distributions for per capita intakes (of fruits and vegetables) for various population groups. The data for the "Whole Population" group was selected for developing the distribution. It was assumed that the intake values in EPA Table 9-3 (g/kg-day) are linearly proportional to produce consumption rates, such that scaling the mean value in EPA Table 9-3 (i.e., 1.6 g/kg-day) to match our recommended deterministic value of 200 kg/yr provides an appropriate distribution for produce consumption. The scaled distribution data was then plotted on a curve.

Next, a GoldSim stochastic element was created that closely reflected the scaled values from the EPA distribution. Figure 7.2-2 shows the scaled EPA distribution and the GoldSim distribution that was developed for use in dose modeling. Details for the GoldSim distribution are provided in Table 7.1-2.

Figure 7.2-2: Developed Distribution Curve for Produce Consumption Rate



7.2.1.4 Meat Consumption Rate

Tables 11-7 through 11-9 of the EPA's *Exposure Factors Handbook* provide a number of mean consumption rates for meats based on surveys taken over various periods of time. [EPA-600-R-090-052F] As with human water consumption, the "All Ages" values were selected as representative of the dose receptors (MOP and IHI). Details for the GoldSim distribution are provided in Table 7.2-1.

Further it is acknowledged that "meat" is a fairly broad term. For this dose methodology the term "meat" is assumed to be all meats that are not classified as poultry or fish. Therefore, "meats" include beef, pork, lamb, veal, sausages, deli meats, and meat mixtures. Based on this approach, the sum of the meat intake for each survey period was determined as follows:

- Meat intake for the 1977-1978 survey was 168 g/day
- Meat intake for the 1987-1988 survey was 150 g/day
- Meat intake for the 1994 survey was 155 g/day
- Meat intake for the 1995 survey was 163 g/day

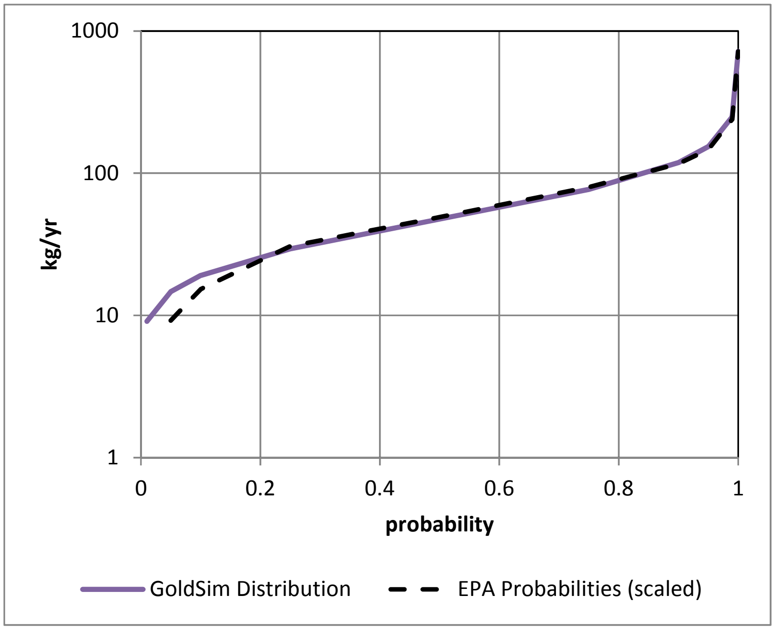
The 1977-1978 survey shows the highest intake rate (168 g/day or approximately 61.4 kg/yr). Therefore, this value was conservatively selected as the recommended value for the total meat consumption rate to use in deterministic modeling.

The probabilistic distribution for human meat consumption was developed based on EPA Table 11-4 of the EPA's *Exposure Factors Handbook*. [EPA-600-R-090-052F] This EPA table shows distributions for consumer-only intakes (of meat) for various population groups. The data for the "Whole Population" group was selected for developing the distribution. It was assumed that the intake values in Table 11-4 (g/kg-day) are linearly proportional to meat

consumption rates, such that scaling the mean value in EPA Table 11-4 (i.e., 2.0 g/kg-day) to match our recommended deterministic value of 61.4 kg/yr provides an appropriate distribution for meat consumption. The scaled distribution data was then plotted on a curve.

Next, a GoldSim stochastic element was created that closely reflected the scaled values from the EPA distribution. Figure 7.2-3 shows the scaled EPA distribution and the GoldSim distribution that was developed for use in dose modeling. Details for the GoldSim distribution are provided in Table 7.2-3.

Figure 7.2-3: Developed Distribution Curve for Meat Consumption Rate



7.2.1.5 Milk Consumption Rate

Tables 11-11 through 11-12 of the EPA's *Exposure Factors Handbook* provide a number of mean consumption rates for milk based on surveys taken over various periods of time. [EPA-600-R-090-052F] As with human water consumption, the "All Ages" values were selected as representative of the dose receptors (MOP and IHI). Based on this approach, the total fluid milk consumptions rates for each survey period were determined as follows:

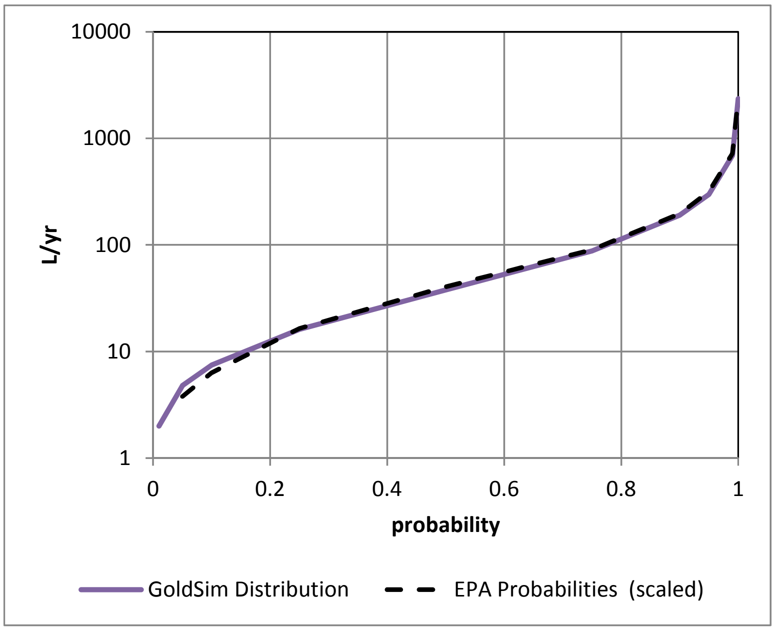
- Milk intake for the 1987-1988 survey was 224 g/day
- Milk intake for the 1994 survey was 229 g/day
- Milk intake for the 1995 survey was 236 g/day

The 1995 survey shows the highest intake rate (236 g/day). Assuming the density of milk is 1.03 kg/L this converts to approximately 83.7 L/yr. The assumed milk density value is based on Section 5.2 of WSRC-STI-2007-00004, Revision 4. Therefore, this value was conservatively selected as the recommended value for the total milk consumption rate to use in deterministic modeling.

The probabilistic distribution for human milk consumption was developed based on EPA Table 11-4 of the EPA's *Exposure Factors Handbook*. [EPA-600-R-090-052F] This EPA table shows distributions for consumer-only intakes (of total dairy) for various population groups. The data for the "Whole Population" group was selected for developing the distribution. It was assumed that the intake values in EPA Table 11-4 (g/kg-day) are linearly proportional to milk consumption rates, such that scaling the mean value in EPA Table 11-4 (i.e., 6.6 g/kg-day) to match our recommended deterministic value of 84 L/yr provides an appropriate distribution for milk consumption. The scaled distribution data was then plotted on a curve.

Next, a GoldSim stochastic element was created that closely reflected the scaled values from the EPA distribution. Figure 7.2-4 shows the scaled EPA distribution and the GoldSim distribution that was developed for use in dose modeling. Details for the GoldSim distribution are provided in Table 7.2-1.

Figure 7.2-4: Developed Distribution Curve for Milk Consumption Rate



7.2.1.6 Poultry Consumption Rate

Tables 11-7 through 11-9 of the EPA's *Exposure Factors Handbook* provide a number of mean consumption rates, including poultry, based on surveys taken over various periods of time. [EPA-600-R-090-052F] As with human water consumption, the "All Ages" values were selected as representative of the dose receptors (MOP and IHI). Based on this approach, the poultry intake for each survey period was determined as follows:

- Poultry intake for the 1977-1978 survey was 27 g/day
- Poultry intake for the 1987-1988 survey was 26 g/day
- Poultry intake for the 1994 survey was 29 g/day

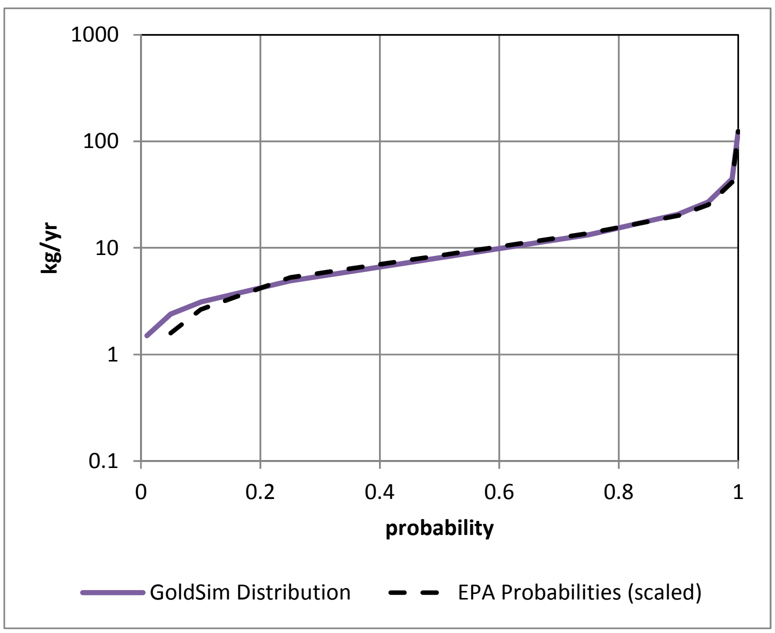
- Poultry intake for the 1995 survey was 24 g/day

The 1994 survey shows the highest intake rate (29 g/day or approximately 10.6 kg/yr). Therefore, this value was conservatively selected as the recommended value for the poultry consumption rate to use in deterministic modeling.

The probabilistic distribution for human poultry consumption was developed based on Table 11-4 of the EPA's *Exposure Factors Handbook*. [EPA-600-R-090-052F] This EPA table shows distributions for consumer-only intakes (of meat) for various population groups. The data for the "Whole Population" group was selected for developing the distribution. It was assumed that the total meat intake values in EPA Table 11-4 (g/kg-day) are linearly proportional to poultry consumption rates of poultry, such that scaling the mean value in EPA Table 11-4 (i.e., 2.0 g/kg-day) to match our recommended deterministic value of 10.6 kg/yr provides an appropriate distribution for poultry consumption. The scaled distribution data was then plotted on a curve.

Next, a GoldSim stochastic element was created that closely reflected the scaled values from the EPA distribution. Figure 7.2-5 shows the scaled EPA distribution and the GoldSim distribution that was developed for use in dose modeling. Details for the GoldSim distribution are provided in Table 7.2-1.

Figure 7.2-5: Developed Distribution Curve for Poultry Consumption Rate



7.2.1.7 Egg Consumption Rate

Tables 11-11 through 11-12 of the EPA's *Exposure Factors Handbook* provide a number of mean consumption rates for eggs based on surveys taken over various periods of time. [EPA-600-R-090-052F] As with human water consumption, the "All Ages" values were

selected as representative of the dose receptors (MOP and IHI). Based on this approach, the egg consumption rates for each survey period were determined as follows:

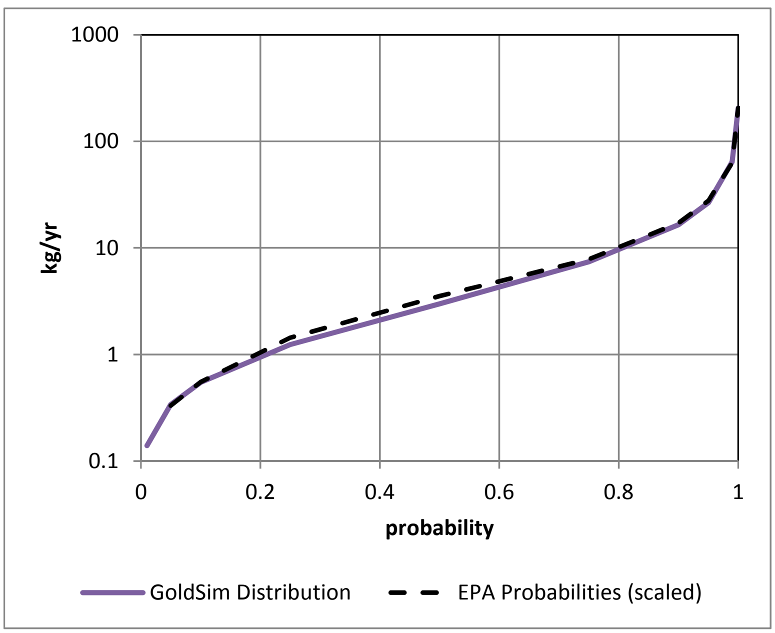
- Egg intake for the 1987-1988 survey was 20 g/day
- Egg intake for the 1994 survey was 17 g/day
- Egg intake for the 1995 survey was 19 g/day

The 1987-1988 survey shows the highest intake rate (20 g/day or approximately 7.3 kg/yr). Therefore, this value was conservatively selected as the recommended value for the total egg consumption rate to use in deterministic modeling.

The probabilistic distribution for human egg consumption was developed based on Table 11-4 of the EPA's *Exposure Factors Handbook*. [EPA-600-R-090-052F] This EPA table shows distributions for consumer-only intakes (of total dairy) for various population groups. The data for the "Whole Population" group was selected for developing the distribution. It was assumed that the intake values in EPA Table 11-4 (g/kg-day) are linearly proportional to egg consumption rates, such that scaling the mean value in EPA Table 11-4 (i.e., 6.6 g/kg-day) to match the recommended deterministic value of 7.3 kg/yr provides an appropriate distribution for egg consumption. The scaled distribution data was then plotted on a curve.

Next, a GoldSim stochastic element was created that closely reflected the scaled values from the EPA distribution. Figure 7.2-6 shows the scaled EPA distribution and the GoldSim distribution that was developed for use in dose modeling. Details for the GoldSim distribution are provided in Table 7.2-1.

Figure 7.2-6: Developed Distribution Curve for Egg Consumption Rate



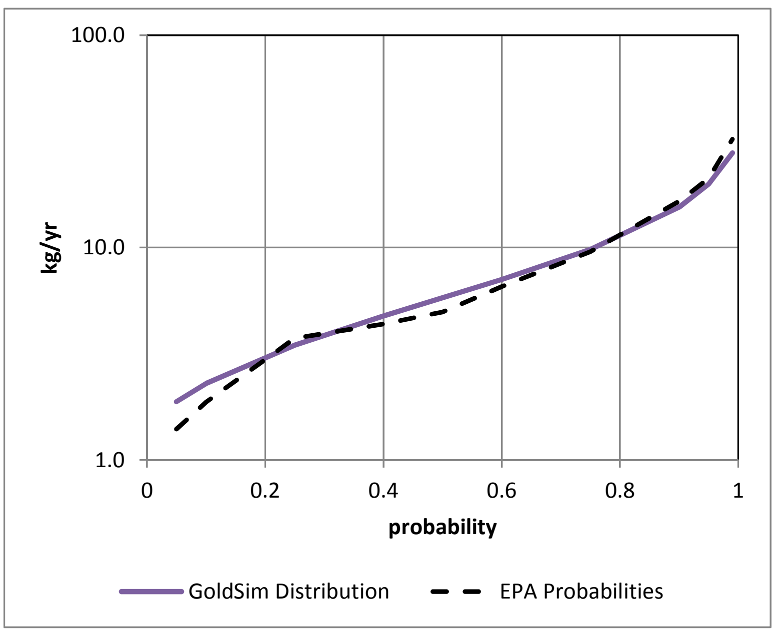
7.2.1.8 Fish Consumption Rate

The recommended value for a fish consumption rate is based on Table 10-7 of the EPA's *Exposure Factors Handbook*. [EPA-600-R-090-052F] This table shows a mean per capita intake of 0.15 g/kg-day by adults 20 to 49 years of age and 0.20 by adults aged 50 years or more. Applying the average of these two values (0.175 g/kg-day) to the average mass of a human adult (i.e., 80 kg from Table 8-1 of the EPA's *Exposure Factors Handbook*) results in a consumption rate of 14 g/day. [EPA-600-R-090-052F]. However, EPA Table 10-13 also shows that residents of the South Atlantic region of the United States have a regionally higher consumption rate of fish (about 6 % higher). For conservatism, it is recommended that the 14 g/day be increased by 10 % (15.4 g/day or about 5.62 kg/yr) to account for this regional variability.

The probabilistic distribution for human fish consumption was also developed based on Table 10-23 of the EPA's *Exposure Factors Handbook*. [EPA-600-R-090-052F] This EPA table shows distributions for all adult fish consumers. It was assumed that the distribution of this table is linearly proportional to the regional fish consumption rate, such that scaling the mean value in EPA Table 10-23 (i.e., 37 g/day) to match the recommended deterministic value of 5.62 kg/yr provides an appropriate distribution for fish consumption.

A GoldSim stochastic element was created that closely reflected the values from the scaled EPA distribution. Figure 7.2-7 shows the EPA distribution and the GoldSim distribution that was developed for use in dose modeling. Details for the GoldSim distribution are provided in Table 7.2-1.

Figure 7.2-5: Developed Distribution Curve for Fish Consumption Rate



7.2.1.9 Human Inhalation Rate

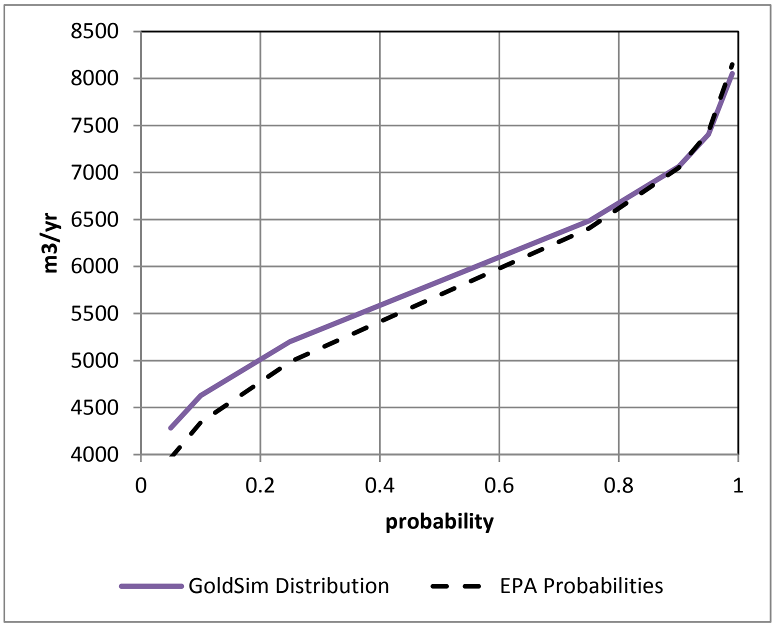
Table 6-31 of the EPA's *Exposure Factors Handbook* provides the basis for the human inhalation rate. [EPA-600-R-090-052F] Based on this table, the total daily average

inhalation rate for an adult is 16 m^3/day (or 5,844 m^3/yr). This value was selected as the recommended value for the human breathing rate to use in deterministic modeling.

The probabilistic distribution for human inhalation was developed based on Table 6-6 of the EPA's *Exposure Factors Handbook*. [EPA-600-R-090-052F] This EPA table shows distributions for daily inhalation rates for various population groups. The data for the normal weight males, aged 40.1 to 70 was selected as the most representative group for developing the distribution because this distribution most closely resembled the average distribution of all adults. This distribution data was then plotted on a curve.

Next, a GoldSim stochastic element was created that closely reflected the scaled values from the EPA distribution. Figure 7.2-6 shows the scaled EPA distribution and the GoldSim distribution that was developed for use in dose modeling. Details for the GoldSim distribution are provided in Table 7.2-1.

Figure 7.2-6: Developed Distribution Curve for Inhalation Rate



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 no probability sampling is recommended for the poultry and egg parameters.

These uptake parameters 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 7.2-2: Other Uptake Parameters

Parameter	Symbol in Equations	Unit [a]	Value [b]	Probabilistic Value			
				Distribution	Mode	Min	Max
meat consumption of water	$Q_{H2O,MEAT}$	L/yr	1.02E+04[c]	Triangular	1.02E+04	1.02E+04	1.83E+04
meat consumption of fodder	$Q_{fod,MEAT}$	kg/yr	1.31E+04[c]	Triangular	1.31E+04	9.86E+03	1.83E+04
milk cow consumption of water	$Q_{H2O,MILK}$	L/yr	1.83E+04[c]	Triangular	1.83E+04	1.83E+04	2.19E+04
milk cow consumption of fodder	$Q_{fod,MILK}$	kg/yr	1.9E+04[c]	Triangular	1.90E+04	1.31E+04	2.01E+04
poultry consumption of water	$Q_{H2O,POULTRY}$	L/yr	1.10E+02[d]	N/A	N/A	N/A	N/A
poultry consumption of fodder	$Q_{fod,POULTRY}$	kg/yr	3.65E+01[d]	N/A	N/A	N/A	N/A
poultry consumption of soil	$Q_{SOIL,POULTRY}$	kg/yr	3.65E+00[d]	N/A	N/A	N/A	N/A
egg consumption of water	$Q_{H2O,EGG}$	L/yr	1.10E+02[d]	N/A	N/A	N/A	N/A
egg consumption of fodder	$Q_{fod,EGG}$	kg/yr	3.65E+01[d]	N/A	N/A	N/A	N/A
egg consumption of soil	$Q_{SOIL,EGG}$	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

Table 7.2-3: Uptake Fractions for Biotic Receptors

Parameter	Symbol in Equations	Value [a]	Probabilistic Value			
			Distribution	Mode	Min	Max
fraction for meat consumption of water	$F_{fod,MEAT}$	0.75[b]	Triangular	0.75	0.5	1.0
fraction for milk consumption of fodder	$F_{fod,MILK}$	0.56[b]	Triangular	0.56	0.5	1.0
fraction for poultry consumption of fodder	$F_{fod,POULTRY}$	1[c]	N/A	N/A	N/A	N/A
fraction for poultry consumption of soil	$F_{SOIL,POULTRY}$	1[c]	N/A	N/A	N/A	N/A
fraction for egg consumption of fodder	$F_{fod,EGG}$	1[c]	N/A	N/A	N/A	N/A
fraction for egg consumption of soil	$F_{SOIL,EGG}$	1[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 water consumption 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).

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 an element 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, 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, this report examined the probabilities and the minimum and maximum values to develop a different (i.e., simplified, but 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, SRR-CWDA-2010-00128, and MDL-MGR-MD-000001.

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 for Revision 1 of the HTF PA using data from SRNL-STI-2010-00447, PNNL-13421, and IAEA-472. [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 geometric 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 geometric log-normal distribution for soil-to-plant transfers. [ML090720287] The 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 sampled multiplier were developed based on various ratios between recommended, minimum, and maximum values.

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 come from Revision 1 of the HTF PA. [SRR-CWDA-2010-00128]

Revision 1 of the HTF PA represents the first and only 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 indicates using a geometric log-normal distribution. This new distribution was applied to the Liquid Waste PA dose calculator as a multiplier. The 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 sampled 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 7.3-1: 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 Sampled Multiplier

Distribution	Mean (geom.)	S.D (geom.)		Min	Max
Geometric 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.

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 Sampled Multiplier

Distribution	Mean (geom.)	S.D (geom.)		Min	Max
Geometric 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 come from Revision 1 of the HTF PA. [SRR-CWDA-2010-00128]

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 geometric log-normal distribution. This new distribution was applied to the dose calculator as a multiplier. The 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 sampled 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 come from the HTF PA. [SRR-CWDA-2010-00128] 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 Sampled Multiplier

Distribution	Mean (geom.)	S.D (geom.)	Min	Max
Geometric 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 come from Revision 1 of the HTF PA. [SRR-CWDA-2010-00128] 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 come from Revision 1 of the HTF PA. [SRR-CWDA-2010-00128]

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 geometric log-normal distribution. This new distribution was applied to the dose calculator as a multiplier. The 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 sampled multiplier were developed based on various ratios between recommended, minimum, and maximum values from various sources.

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 cutting 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 to these parameters. Recommendations for these parameters are provided in Table 7.4-1.

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 Sampled Multiplier

Distribution	Mean (geom.)	S.D (geom.)	Min	Max
Geometric 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.

Table 7.4-1: Exposure and Inhalation Parameters

Parameter	Symbol in Equations	Unit	Value [a]	Probabilistic Value				
				Distribution	Mean / Mode	SD	Min	Max
fraction of time spent in a contaminated garden	$F_{t,g}$	none	2.7E-02 [b]	Triangular	2.7E-02	N/A	1.3E-02	5.4E-02
fraction of time spent showering or bathing	$F_{t,SHOWER}$	none	1.2E-02 [b]	Log-Normal	1.2E-02	6.9E-03	2.1E-03	4.2E-02
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	1.0E-03 [b]	Triangular	1.0e-03	N/A	0	4.1E-03
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	2.3E-03	N/A	2.3E-04	4.6E-03
airborne release fraction	ARF	none	1.0E-4 [f]	Uniform	N/A	N/A	4.0E-6	2.0E-4
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

a This is the recommended value, for use in deterministic modeling.
b See discussion in Section 7.4.1.
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
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 ARF 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).

7.4.1 Explanation of Selected Fractions

Fraction of time in garden

Table 16-100 of the EPA's *Exposure Factors 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 Table 13-71 of the EPA's *Exposure Factors Handbook* indicates that 31% of all households have gardens). This results in recommended a fractional value of 0.027 (0.0083 ÷ 0.31).

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

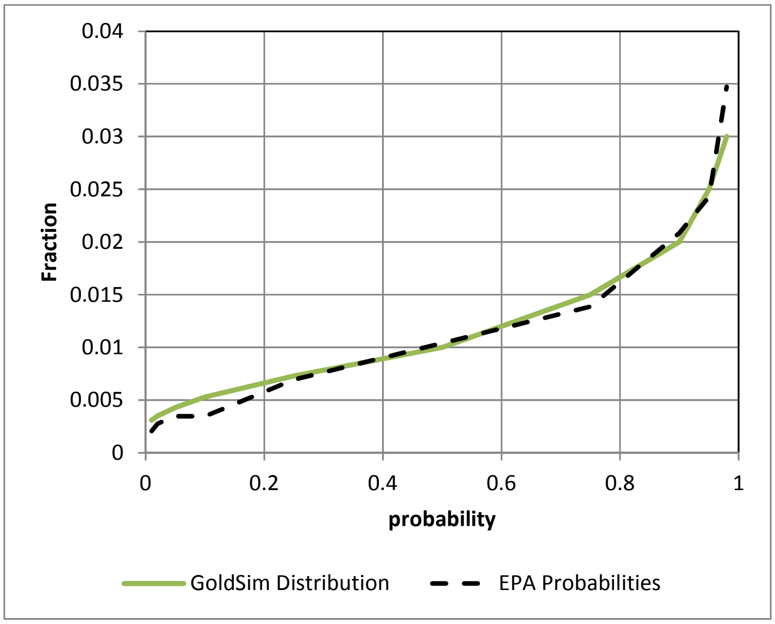
Fraction of time in shower

Table 16-30 of the EPA's *Exposure Factors Handbook* indicates that the average adult spends 17.1 min/day bathing and showering. [EPA-600-R-090-052F] Given 24 hr/day and 60 min/hr, this results in a recommended fractional value of 0.012 (17.1 min/day ÷ (60 min/hr × 24 hr/day)).

The recommended distribution was developed based on Table 16-32 of the EPA's *Exposure Factors Handbook*. [EPA-600-R-090-052F] The values were converted into fractional values by dividing the values by 1,440 min/day.

Finally, a GoldSim stochastic element was created that closely reflected the converted values from the EPA distribution. Figure 7.4-1 shows the scaled EPA distribution and the GoldSim distribution that was developed for use in dose modeling. Details for the GoldSim distribution are provided in Table 7.4-1.

Figure 7.4-1: Developed Distribution Curve for Fraction of Time Spent Showering



<u>**Fraction of time swimming**</u>

Table 16-1 of the EPA's *Exposure Factors Handbook* recommends an average swim time of 45 min/mon for adults. [EPA-600-R-090-052F] Given 12 mon/yr and 525,960 min/yr, this results in a recommended fractional value of 1.0E-03 ((45 min/mon × 12 mon/yr) ÷ 525,960 min/yr).

Given the limited data about swim times, a simple triangular sampling distribution is assumed for probabilistic modeling, where the mode is equal to the recommended value, the minimum is zero, and the maximum value is 4.1E-03 (based on the 181 min/mon reported for the 95^{th} percentile of the recommended swim time (from EPA Table 16-1)).

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 Value				
				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	240	17	180	270
dry bulk density of soil	ρ_S	kg/m^3	1650 [c]	Normal	1650	120	1400	1900
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	1.32	N/A	0.76	2.0
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	18.1	N/A	11	18.1
soil moisture content	MC_{soil}	none	0.2086[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	1.0E-7	N/A	1.0E-8	3.0E-7

[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 Value				
				Distribution	Mean / Mode	SD	Min	Max
fraction of material deposited on leaves that is retained	F_r	unitless	0.25 [b]	Triangular	0.25	N/A	0.2	0.25
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	1.92E-01	1.92E-02	1.64E-01	2.46E-01
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	2.2	0.5	0.2	4
depth of crop garden tilling	d_{till}	m	0.15	Triangular	0.15	N/A	0.15	0.61
fraction of produce that is leafy	F_L	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	100	N/A	100	1000

[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 Value				
				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	55.8	32	9.1	305

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 Section 7.5.3.1, below.

7.5.3.1 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]

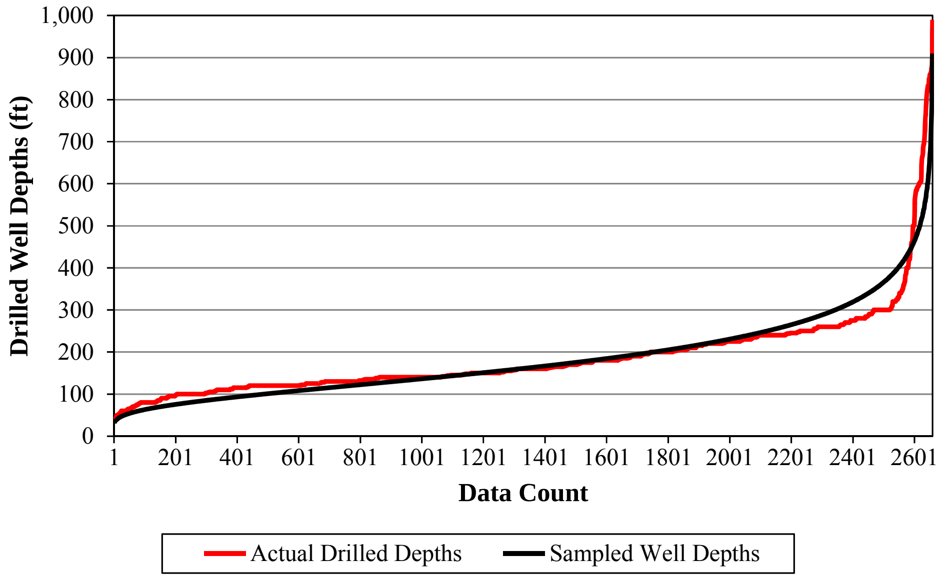
Alternatively, the CompletionStratum element in GoldSim was used to modify the ground water concentrations for the MOP and Chronic IHI dose calculations based on well depths. This modifier was determined based on appropriate modeling results for aquifer flow and transport, which showed that contaminant 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.

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 truncated log-normal distribution, with a mean value of 185 feet (55.8 m), a minimum depth of 30 feet (9.1 m), a maximum depth of 1,000 feet (305 m), and a standard deviation of 105 feet (32 m). Figure 7.5-1 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.

Figure 7.5-1: Well Depth Sampling Comparison



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 and drink intake that is home-produced, as opposed to other sources. Table 7.6-1 provides a summary of the recommended values. With the exception of the local water fraction these parameters all come directly from the EPA's *Exposure Factors Handbook*. [EPA-600-R-090-052F, Table 13-68] Also, all of these parameters assume that the MOP and IHI receptors are adults. The MOP receptor is assumed to be from a household that gardens and raises animals. The IHI receptor is assumed to be from a household that farms. Both are assumed to fish locally.

For sampling, the recommended minimum for all of these fractions (except the local water fraction) is assumed to be 0.1 and the maximum is assumed to be double the recommended value. Due to lack of guidance, a triangular distribution is assumed where the recommended value is the mode.

An EPA drinking water survey was used to develop the values for the local water fraction. [EPA-822-R-00-001] The EPA drinking water survey reports that 75 % of ingested water comes from community water, 13 % from bottled water, 10 % from other sources (well, spring, and cistern, etc.), and 2 % from non-identified sources. For conservatism, the fraction provided below assumes that the community water, the other sources, and the non-identified sources are contaminated such that the recommended fraction is 0.87 (i.e., 75 % + 10 % + 2%). The maximum assumes that all water consumed is contaminated and the minimum assumes that only the community water is consumed.

Table 7.6-1: Recommended Fractional Values for Local Productivity

Fraction of Foodstuff Produced Locally		MOP or IHI?	Mode	Min	Max
Symbol in Equations	Parameter Description				
$F_{local,H2O}$	The fraction consumed water that comes from the contaminated water source.	MOP and IHI	0.87	0.75	1.0
$F_{local,PLANT}$	The fraction of total produce grown at home. [a]	MOP	0.173	0.1	0.346
$F_{IHI,local,PLANT}$		IHI	0.308	0.1	0.616
$F_{local,MEAT}$	The fraction of total meats produced at home.	MOP	0.306	0.1	0.612
$F_{IHI,local,MEAT}$		IHI	0.319	0.1	0.638
$F_{local,MILK}$	The fraction of total milk produced at home.	MOP	0.207	0.1	0.414
$F_{IHI,local,MILK}$		IHI	0.254	0.1	0.508
$F_{local,POULTRY}$	The fraction of total poultry produced at home.	MOP	0.151	0.1	0.302
$F_{IHI,local,POULTRY}$		IHI	0.156	0.1	0.312
$F_{local,EGG}$	The fraction of total eggs produced at home.	MOP	0.214	0.1	0.428
$F_{IHI,local,EGG}$		IHI	0.146	0.1	0.292
$F_{local,FISH}$	The fraction of households that fish.	MOP and IHI	0.325	0.1	0.650

[EPA-822-R-00-001 and EPA-600-R-090-052F]

a The EPA's *Exposure Factors Handbook* gives separate fractions for vegetables and for fruits. [EPA-600-R-090-052F] Because the effective dose factor for produce consumption adds fruit consumption to vegetable consumption for a single produce consumption value (Equation 3.1-4a), the higher fraction for local productivity is assumed as a conservative simplification.

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	0.3	a	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
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 geometric lognormal distribution is recommended. [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 95^{th} 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 A 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

DOE G 435.1-1, *Implementation Guide for use with DOE M 435.1-1*, U.S. Department of Energy, Washington DC, July 9, 1999.

DOE-HDBK-3010-94, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities, Volume 1 - Analysis of Experimental Data,* U.S. Department of Energy, Washington DC, December 1994.

DOE/ID-10966, *Performance Assessment for the Tank Farm Facility at the Idaho National Engineering and Environmental Laboratory*, Idaho National Laboratory, Idaho Falls, ID, Rev. 1, April 2003.

DOE-STD-1196-2011, *DOE Standard Derived Concentration Technical Standard*, U.S. Department of Energy, Washington, DC, April 2011.

EPA-600-R-090-052F, *Exposure Factors Handbook, 2011 Edition*, U.S. Environmental Protection Agency, Washington DC, September 2011.

EPA-402-R-93-081, *Federal Guidance Report No. 12, External Exposure to Radionuclides in Air, Water, and Soil*, U.S. Environmental Protection Agency, Washington DC, September 1993.

EPA-402-R-99-001, *Federal Guidance Report No. 13, Cancer Risk Coefficients for Environmental Exposure to Radionuclides*, U.S. Environmental Protection Agency, Washington DC, September 1999.

EPA-520-1-88-020, *Federal Guidance Report No. 11, Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, U.S. Environmental Protection Agency, Washington DC, September 1988.

EPA-822-R-00-001, *Estimated Per Capita Water Ingestion and Body Weight in the United States - An Update, Based on Data Collected by the United States Department of Agriculture's 1994 - 1996 and 1998 Continuing Survey of Food Intakes by Individuals,* U.S. Environmental Protection Agency, Washington DC, October 2004.

HNF-SD-WM-TI-707, *Exposure Scenarios and Unit Dose Factors for Hanford Tank Waste Performance Assessments*, Fluor Federal Services, Richland, WA, Rev. 3, July 2003.

IAEA-472, (Copyright), *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments, Technical Reports Series No. 472*, International Atomic Energy Agency, Vienna, January 2010.

ICRP-72 (Copyright), *Radiation Protection: ICRP Publication 72 - Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Dose Coefficients*, International Commission on Radiological Protection, Didcot, Oxfordshire, September 1996.

MDL-MGR-MD-000001, Sandia National Laboratories, *Biosphere Model Report*, MDL-MGR-MD-000001, Rev 02, [ML090720287] Las Vegas, NV, August 2007.

ML073510127, *Recommended Site-Specific Sorption Coefficients for Reviewing Non-High-Level Waste Determinations at the Savannah River Site and Idaho National Laboratory*, U.S. Nuclear Regulatory Commission, Washington DC, October 2007.

ML083190829, Simpkins, A.A., et al., *Description of Methodology for Biosphere Dose Model BDOSE,* U.S. Nuclear Regulatory Commission, Washington DC, Rev. 1, November 30, 2008.

NUREG_CR-5512, Kennedy, W.E., Jr., et al., *Residual Radioactive Contamination From Decommissioning, Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent, Final Report*, Vol. 1, U.S. Nuclear Regulatory Commission, Washington DC, October 1992.

ORNL-5786, Baes, C.F., III, et al., *A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture*, Oak Ridge National Laboratory, Oak Ridge, TN, September 1984.

PNNL-13421, Staven, L.H., et al., *A Compendium of Transfer Factors for Agricultural and Animal Products*, Pacific Northwest Laboratory, Richland, WA, June 2003.

Regulatory Guide 1.109, *Calculation of Annual Doses to Man From Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR 50,* Appendix I, U.S. Nuclear Regulatory Commission, Washington DC, Rev. 1, October 1977.

SRNL-STI-2009-00150, McDowell-Boyer, L., et al., *Distribution Coefficients (K_ds), K_d Distributions, and Cellulose Degradation Product Correction Factors for the Composite Analysis,* Savannah River Site, Aiken, SC, Rev. 1, April 2009.

SRNL-STI-2009-00473, Kaplan, D.I., *Geochemical Data Package for Performance Assessment Calculations Related to the Savannah River Site*, Savannah River Site, Aiken, SC, March 15, 2010.

SRNL-STI-2010-00447, Jannik, G.T., et al., *Land and Water Use Characteristics and Human Health Input Parameters for Use in Environmental Dosimetry and Risk Assessments at the Savannah River Site*, Savannah River Site, Aiken, SC, Rev. 0, August 6, 2010.

SRNL-STI-2010-00493, Seaman, J.C., and Kaplan, D.I., *Chloride, Chromate, Silver, Thallium, and Uranium Sorption to SRS Soils, Sediments, and Cementitious Materials*, Savannah River Site, Aiken, SC, Rev. 0, September 29, 2010.

SRNL-STI-2011-00011, Kaplan, D.I, *Estimated Neptunium Sediment Sorption Values as a Function of pH and Measured Barium and Radium K_d Values*, Savannah River Site, Aiken, SC, Rev. 0, January 23, 2011.

SRNL-STI-2011-00672, Almond, P.M., et al., *Variability of Kd Values in Cementitious Materials and Sediments*, Savannah River Site, Aiken, SC, Rev. 0, January 2012.

SRNS-STI-2008-00286, Kaplan, D.I., et al., *Range and Distribution of Technetium K_d Values in the SRS Subsurface Environment*, Savannah River Site, Aiken, SC, Rev. 1, October 28, 2008.

SRR-CWDA-2009-00017, *Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site,* Savannah River Site, Aiken, SC, Rev. 0, October 29, 2009.

SRR-CWDA-2010-00054, *Evaluation of Well Drilling Records in the Vicinity of SRS from CY2005 Through CY2009*, Savannah River Site, Aiken, SC, Rev. 0, July 12, 2010.

SRR-CWDA-2010-00128, *Performance Assessment for the H-Area Tank Farm at the Savannah River Site*, Savannah River Site, Aiken, SC, Rev. 1, November 2012.

SRR-CWDA-2012-00106, *Tanks 5 and 6 Special Analysis for the Performance Assessment for the F-Tank Farm at the Savannah River Site*, Savannah River Site, Aiken, SC, Rev. 1, January 2013.

SRS-REG-2007-00002, *Performance Assessment for the F-Tank Farm at the Savannah River Site,* Savannah River Site, Aiken, SC, Rev. 1, March 31, 2010.

SRS-REG-2007-00029, *General Separations Area Well Drilling Probabilities*, Savannah River Site, Aiken, SC, Rev. 0, November 7, 2007.

WSRC-STI-2006-00123, Jannik, G.T. and Dixon, K.L., *LADTAP-PA: A Spreadsheet for Estimating Dose Resulting from E-Area Groundwater Contamination at the Savannah River Site,* Savannah River Site, Aiken, SC, Rev. 0, August 2006.

WSRC-STI-2006-00198, Phifer, M.A., et al., *Hydraulic Property Data Package for the E-Area and Z-Area Soils, Cementitious Materials, and Waste Zones*, Savannah River Site, Aiken SC, Rev. 0, September 2006.

WSRC-STI-2007-00004, Lee, P.L., et al., *Baseline Parameter Update for Human Health Input and Transfer Factors for Radiological Performance Assessments at the Savannah River Site*, Savannah River Site, Aiken, SC, Rev. 4, June 13, 2008.

WSRC-STI-2007-00184, Phifer, M.A., *FTF Closure Cap Concept and Infiltration Estimates,* Savannah River Site, Aiken, SC, Rev. 2, October 15, 2007.

APPENDIX A

ASSESSMENT OF REVISED DOSE CALCULATION METHODOLOGY ON EXISTING PAS

APPENDIX A. ASSESSMENT OF REVISED DOSE CALCULATION METHODOLOGY ON EXISTING PAS

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. These models only used concentrations from the modeling sectors that represented the highest doses over time, ignoring all other sectors. Some modeling parameters (such as K_d values) are used in both concentration calculations and the dose calculations, such that the doses presented here have internally inconsistent values and assumptions. Further, each of the current Liquid Waste PAs evaluated different sets of radionuclides, as is consistent with current inventory screening practices, whereas the doses shown here using the updated dose calculation methodology ignored concentration data for inventories that were not common among all three PAs (as an example dose contributions from Ru-106 were not included in this analysis). Therefore the doses presented here are for comparison purposes only.

This appendix has four sections. Section A1 shows dose comparisons using FTF concentrations. Section A2 shows dose comparisons using HTF concentrations. Section A3 shows dose comparisons using SDF concentrations. Finally Section A4 summarizes the dose comparisons and provides general conclusions.

A1. 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 modeled contaminant transport in two ways: (1) using the Base Case assumptions from the FTF PA, and (2) using updated assumptions for a Composite Sensitivity Study. For consistency only the Base Case concentrations were applied to this updated dose methodology. The following figures present the comparison results using the FTF Base Case concentrations.

These figures show a notable difference in the resulting doses. Of all the recommended changes described within the body of this report, two are identified as being most responsible for driving the reduction in the overall dose results. First, the production yield for crops and gardens increased from 0.7 kg/m^2 to 2.2 kg/m^2, which effectively dilutes the contaminant concentration for the produce ingestion dose by a factor of three. This difference is most noticeable in the doses for the MOP at the 100-meter well. Second, the rate for fish consumption decreased from 9 kg/yr to 5.62 kg/yr, while the local fishing fraction has now been applied to account for the fact that only a percentage of the population actually participates in fishing activities (i.e., some fish that is consumed comes from non-contaminated sources). The application of this local fishing fraction is most pronounced in the comparison of the seepline doses.

Figure A1-1: 100-Meter MOP Dose Comparison Using Concentrations from the Tank 5 and Tank 6 Special Analysis

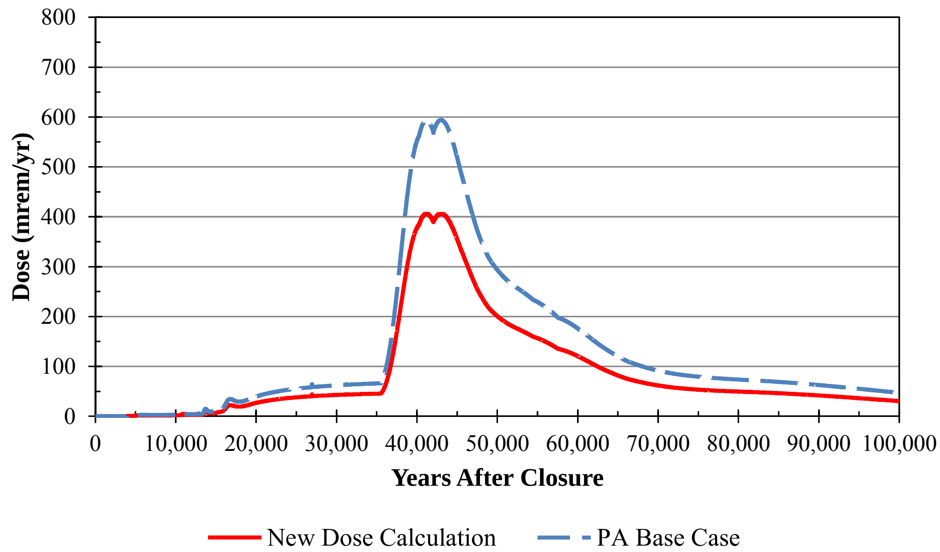


Figure A1-2: Seepline MOP Dose Comparison Using Concentrations from the Tank 5 and Tank 6 Special Analysis

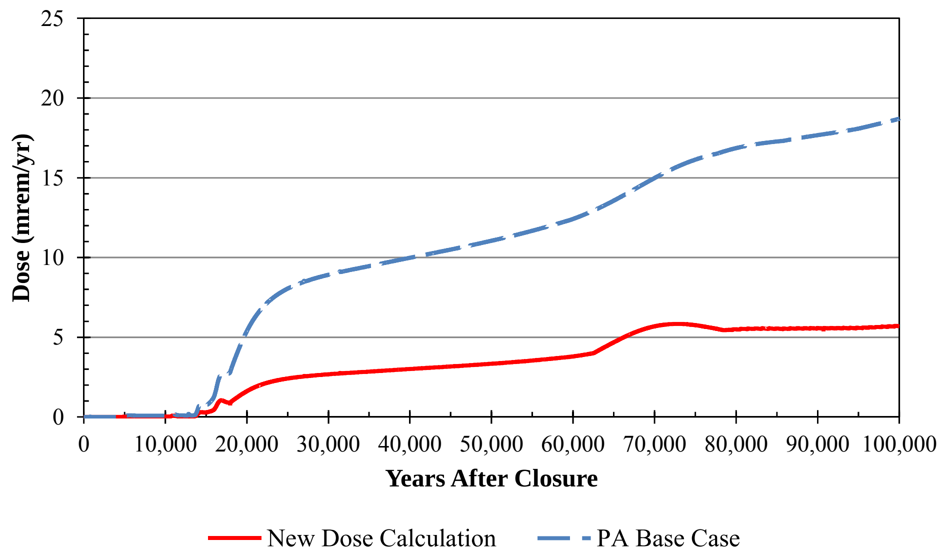


Figure A1-3: Chronic IHI Dose Comparison Using Concentrations from the Tank 5 and Tank 6 Special Analysis

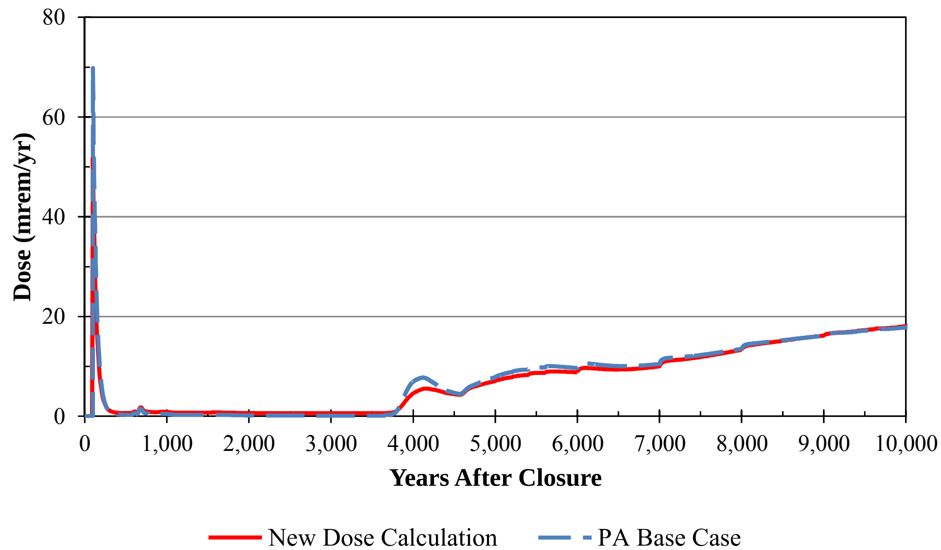
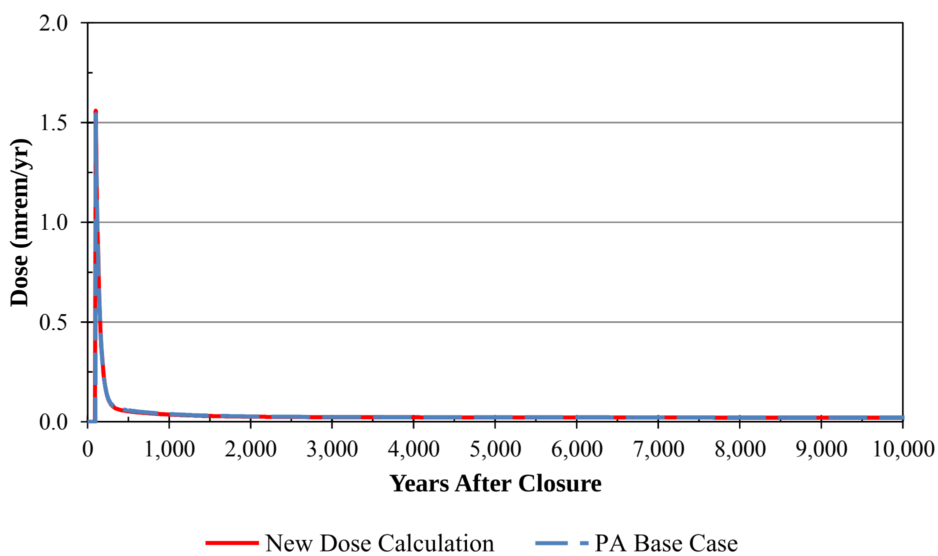


Figure A1-4: Acute IHI Dose Comparison Using Concentrations from the Tank 5 and Tank 6 Special Analysis



A2. 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 figures present the comparison results using the HTF Base Case concentrations. As with the FTF results in A1, the reduction in dose is primarily attributed to updates to the produce and fish ingestion pathways.

Figure A2-1: 100-Meter MOP Dose Comparison Using Concentrations from the HTF PA

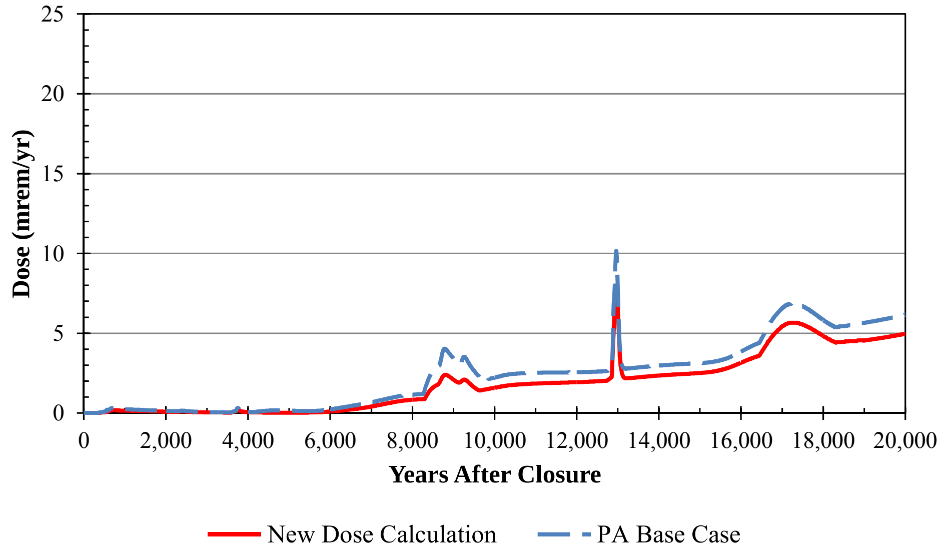


Figure A2-2: Seepline MOP Dose Comparison Using Concentrations from the HTF PA

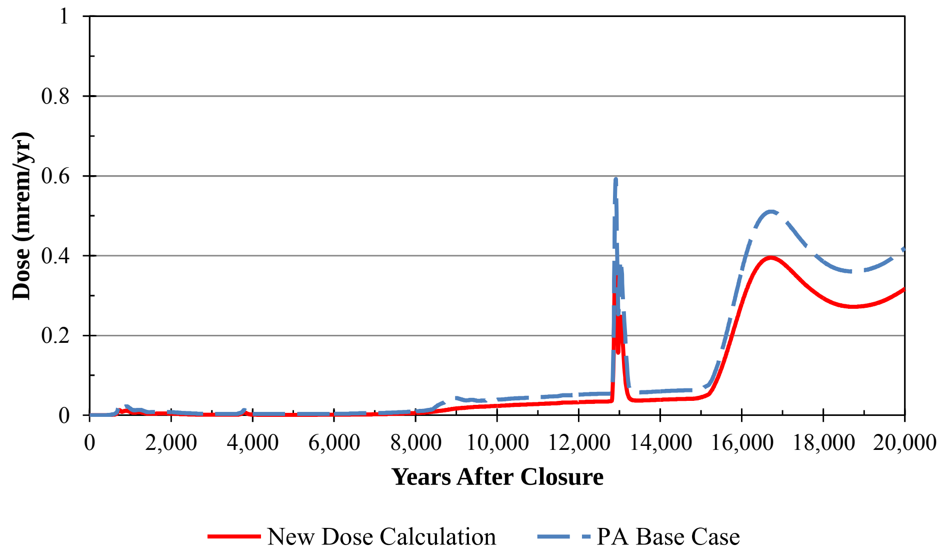


Figure A2-3: Chronic IHI Dose Comparison Using Concentrations from the HTF PA

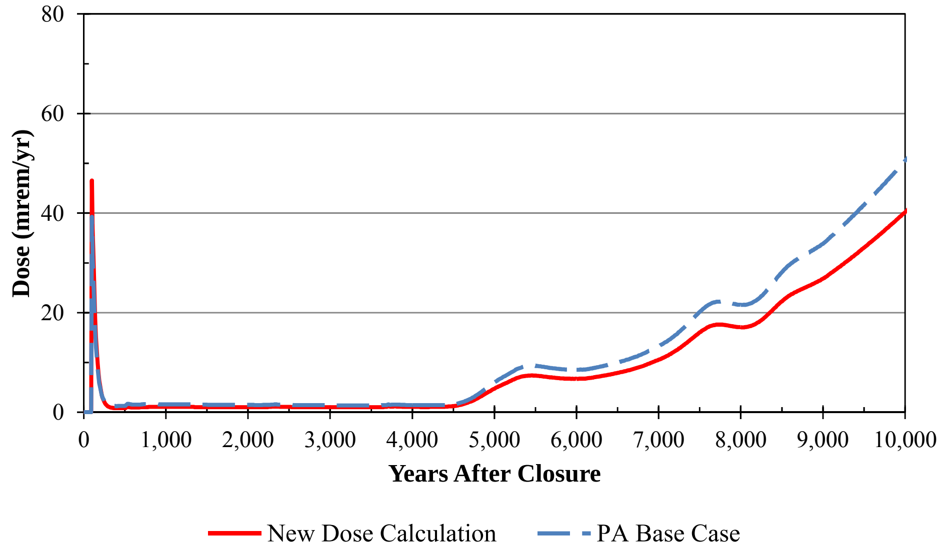
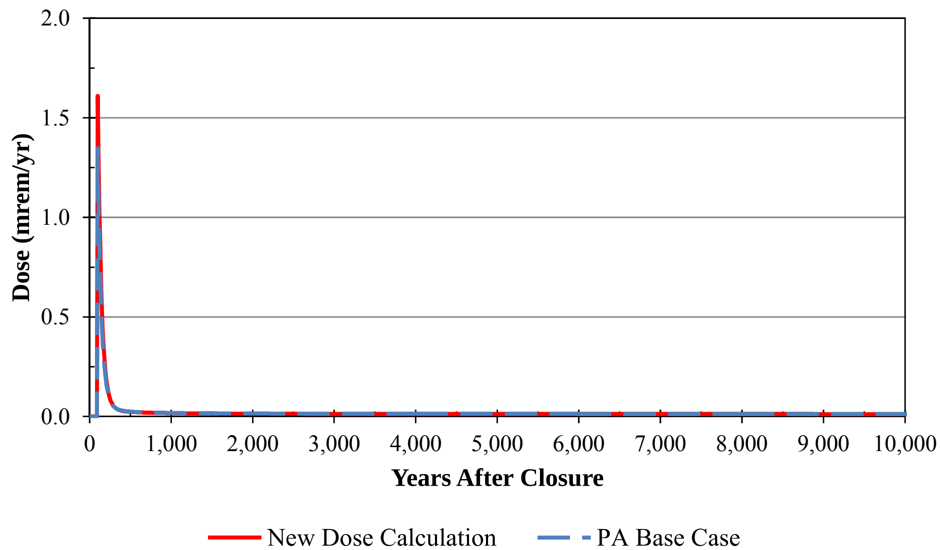


Figure A2-4: Acute IHI Dose Comparison Using Concentrations from the HTF PA



A3. SDF Dose Comparison

At the time of the preparation of this report, the most current SDF contaminant concentrations were determined for Revision 1 of the SDF PA. [SRR-CWDA-2009-00017] Although sensitivity cases have been performed to support responses to questions from reviewers and other activities related to SDF closure, these other modeling cases did not apply Base Case modeling assumptions, so the resulting concentrations are not comparable to those discussed throughout this report. For consistency, only the Base Case concentrations were applied to this updated dose methodology. The following figures present the comparison results using the SDF Base Case concentrations.

As with the FTF results in A1, the reduction in dose is primarily attributed to updates to the produce and fish ingestion pathways.

Note that unlike the FTF PA and the HTF PA comparisons, the SDF comparison does not include the SL MOP results. This comparison was not included because the previous SDF PA did not explicitly provide this data. Additionally note that the SDF PA assumes only groundwater contributions to the chronic intruder (i.e., no drill cuttings), as transfer line inventories are not considered and penetration into the grouted disposal units is assumed to be an unlikely scenario.

Figure A3-1: 100-Meter MOP Dose Comparison Using Concentrations from the SDF PA

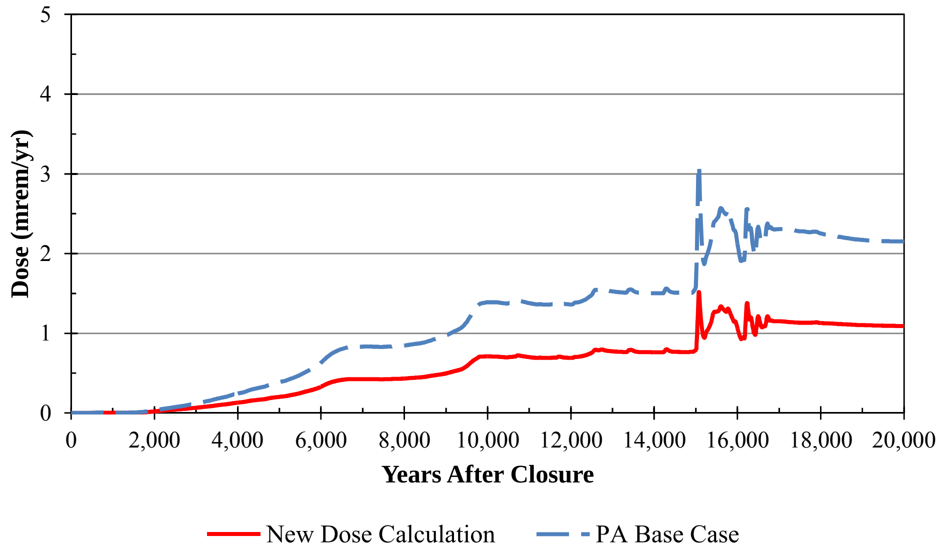


Figure A3-2: Chronic IHI Dose Comparison Using Concentrations from the SDF PA

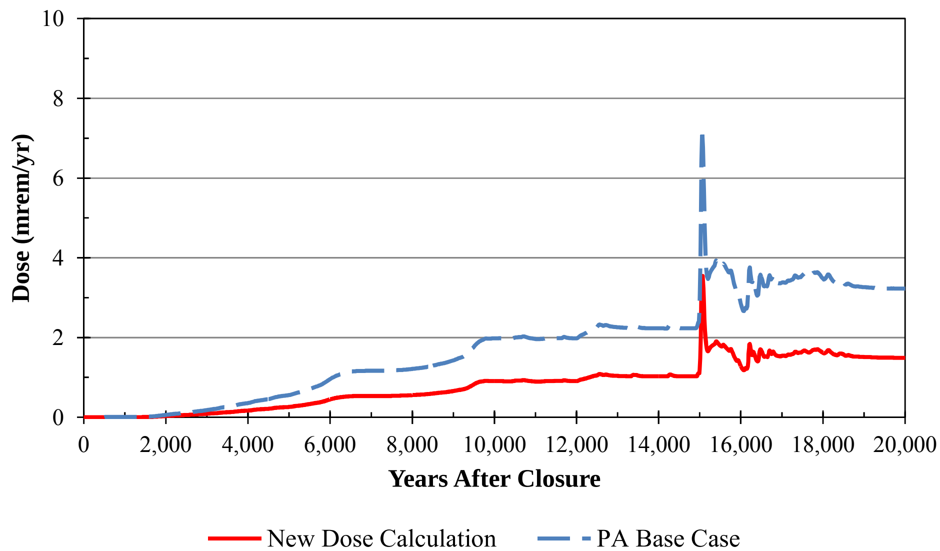
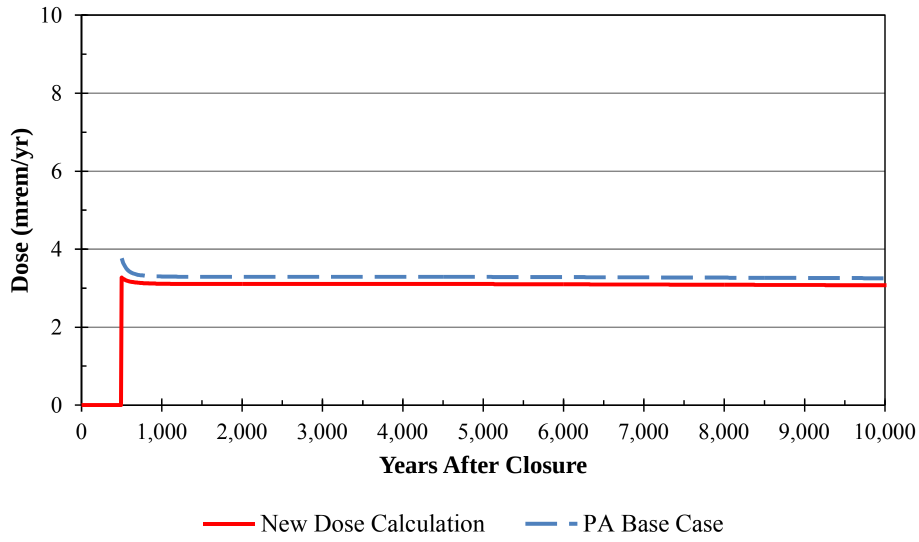


Figure A3-3: Acute IHI Dose Comparison Using Concentrations from the SDF PA



A4. Summary of Dose Comparisons

Table A-1 shows the peak doses for the scenarios that were considered. The revised dose calculation methodology described within this report results in generally lower peak doses for most scenarios. Using the HTF concentrations for the IHI scenarios resulted in increased doses at the assumed time for the human intrusion, which is conservatively modeled as happening 100 years after closure. This is due to the inclusion of drill cutting contributions into more of the pathways via the contaminated garden or crop; however, these increases are only significant at the time of the initial intrusion. Assuming a longer (and arguably more reasonable) period of institutional controls would significantly diminish the impact of this increase as the shorter lived radionuclides decay into more stable daughter products. As such, these increases should not significantly impact any previous PA-related decisions.

Table A-1. Peak Dose Comparisons

	FTF Tank 5/6 SA		HTF PA, Rev. 1		SDF PA, Rev. 0	
1,000 Year Peak Doses	**SA Base Case**	**New**	**PA Base Case**	**New**	**PA Base Case**	**New**
100m MOP	0.42	0.27	0.31	0.18	0.0062	0.0033
SL MOP	0.013	0.007	0.026	0.013	N/A	N/A
Chronic IHI	70	52	39	47	0.0086	0.0042
Acute IHI	1.5	1.6	1.3	1.6	3.8	3.3
10,000 Year Peak Doses	**SA Base Case**	**New**	**PA Base Case**	**New**	**PA Base Case**	**New**
100m MOP	3.3	2.0	4.0	2.4	1.4	0.7
SL MOP	0.099	0.042	0.044	0.024	N/A	N/A
Chronic IHI	70	52	50	47	2.0	0.9
Acute IHI	1.5	1.6	1.3	1.6	3.8	3.3