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December 23, 2016

MEMORANDUM TO: Gregory Suber, Chief
Low Level Waste Branch
Division of Decommissioning,
Uranium Recovery, and Waste Programs

THRU: Christepher McKenney, Chief **/RA/**
Performance Assessment Branch
Division of Decommissioning,
Uranium Recovery, and Waste Programs

FROM: Christopher Grossman, Project Manager
Materials Decommissioning Branch
Division of Decommissioning,
Uranium Recovery, and Waste Programs

SUBJECT: TECHNICAL REVIEW OF "DOSE CALCULATION METHODOLOGY FOR LIQUID WASTE PERFORMANCE ASSESSMENTS AT THE SAVANNAH RIVER SITE", SRR-CWDA-2013-00058, REV. 1, JULY 2014 (DOCKET NO. PROJ0734)

The U.S. Nuclear Regulatory Commission (NRC) staff has performed a technical review of the subject document prepared by the United States Department of Energy (DOE) to support dose calculations for liquid waste performance assessments at the F- and H-Tank Farms (TFs) and Saltstone Disposal Facility (SDF) at the Savannah River Site (SRS). This technical review report supports Monitoring Factors 6.2, "Model and Parameter Support", as detailed in NRC staff's plan for monitoring closure of the SRS TFs (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15238B403). Additionally, this technical review report evaluates DOE's effort to address technical issues identified in Monitoring Factors 10.07, "Calculation of Build-Up in Biosphere Soil," and 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors", as detailed in the NRC staff's plan for monitoring the SDF (ADAMS Accession No. ML13100A076). Finally, issues regarding DOE's selection of sorption coefficients are also relevant to DOE's revised dose calculations. NRC has identified

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that these issues will continue to be monitored under Monitoring Factor 4.1, "Natural Attenuation of Key Radionuclides," listed in NRC staff's SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) and Monitoring Factors 7.01, "Certain Risk-Significant Kd Values in Site Sand and Clay;" and 10.09, "Kd Values for SRS Soil," listed in NRC staff's SDF Monitoring Plan (ADAMS Accession No. ML13100A076).

The Revised Dose Methodology (SRR-CWDA-2013-00058, Rev. 1) generally provides a transparent and traceable documentation of the human receptor definitions, exposure pathways, dose calculations, and parameter values and distributions. Further, the methodology includes an all-pathways exposure scenario that is widely used in performance assessments and is well-suited for the purpose. DOE's calculations are well documented and appropriate for the purpose. However, the NRC staff has identified the need for follow-up actions with respect to DOE's human receptor definition and its relevance for the recommendation of parameter values and distributions and the basis for the recommendation of several parameter values and distributions identified herein. To reach these conclusions, the NRC staff focused on a number of areas listed in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) related to Monitoring Factors 4.1, "Natural Attenuation of Key Radionuclides," and 6.2, "Model and Parameter Support," and in the SDF Monitoring Plan (ADAMS Accession No. ML13100A076) related to Monitoring Factors, 7.01, "Certain Risk-Significant Kd Values in Site Sand and Clay;" 10.07, "Calculation of Build-Up in Biosphere Soil;" 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors;" and 10.09, "Kd Values for SRS Soil".

With respect to DOE's human receptor definition, NRC staff has concerns with DOE's receptor, the reference person because it differs from the average member of the critical group concept. DOE typically relies upon characteristics derived from surveys of the U.S. population as a whole to define its receptor. The average member of the critical group entails an assessment of the more highly exposed individuals in the population, who may have different characteristics than the U.S. population as a whole. NRC staff will continue to monitor DOE's human receptor definition under Monitoring Factor Monitoring Factor 6.2, "Model and Parameter Support," in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) and Monitoring Factor 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors," in the SDF Monitoring Plan (ADAMS Accession No. ML13100A076).

NRC staff's concern with the human receptor definition also resulted in concerns with recommended values for several parameters that quantify the receptor's behavior including consumption rates of water and certain foods, the breathing rate, the fractions of foods produced locally, certain exposure and inhalation parameters, and certain crop and gardening parameters. NRC staff will continue to monitor DOE's behavioral parameters and their applicability to the average member of the critical group under Monitoring Factor 6.2, "Model and Parameter Support," in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) and Monitoring Factor 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors," in the SDF Monitoring Plan (ADAMS Accession No. ML13100A076).

NRC staff also identified concerns with the transparency and traceability of parameter value recommendations other than those summarized above and their supporting basis. These parameters include certain animal uptake parameters, transfer coefficients, exposure and inhalation parameters, and drilling parameters that are identified in the enclosure. NRC staff will continue to monitor DOE's recommended parameter values and their supporting basis for these identified parameters under Monitoring Factor 6.2, "Model and Parameter Support," in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) and Monitoring Factor 10.08, “Consumption Factors and Uncertainty Distributions for Transfer Factors,” in the SDF Monitoring Plan (ADAMS Accession No. ML13100A076).

Some of the items identified in this review that are summarized above have not previously been documented by NRC under either Monitoring Factor 6.2, “Model and Parameter Support,” in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) or Monitoring Factor 10.08, “Consumption Factors and Uncertainty Distributions for Transfer Factors,” in the SDF Monitoring Plan (ADAMS Accession No. ML13100A076). As a result of this review, NRC staff is expanding Monitoring Factor 6.2 for the SRS TFs and Monitoring Factor 10.08 for the SDF to include the items summarized above that were not previously documented.

Enclosure:
Technical Review of the Dose Calculation Methodology for Liquid Waste Performance Assessments at the Savannah River Site

"Consumption Factors and Uncertainty Distributions for Transfer Factors," in the SDF Monitoring Plan (ADAMS Accession No. ML13100A076).

Some of the items identified in this review that are summarized above have not previously been documented by NRC under either Monitoring Factor 6.2, "Model and Parameter Support," in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) or Monitoring Factor 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors," in the SDF Monitoring Plan (ADAMS Accession No. ML13100A076). As a result of this review, NRC staff is expanding Monitoring Factor 6.2 for the SRS TFs and Monitoring Factor 10.08 for the SDF to include the items summarized above that were not previously documented.

Enclosure:
Technical Review of the Dose Calculation Methodology for Liquid Waste Performance Assessments at the Savannah River Site

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

Date: December 23, 2016

Reviewers

Christopher Grossman, Project Manager, U.S. Nuclear Regulatory Commission
Karen Pinkston, Risk Analyst, U.S. Nuclear Regulatory Commission

Primary Document

SRR-CWDA-2013-00058, Revision 1, "Dose Calculation Methodology for Liquid Waste Performance Assessments at the Savannah River Site", July 2014.

Summary of Technical Report

The revised dose calculation methodology for liquid waste performance assessments (PAs) at the Savannah River Site (SRS) builds upon dose calculations and methods for the F-Tank Farm (FTF)[1], H-Tank Farm (HTF)[2], and Saltstone Disposal Facility (SDF)[3] PAs and, rather than superseding biosphere modeling in previous PAs, provides recommendations for process improvements to future biosphere modeling based on more recent information. SRR-CWDA_2013-00058, Rev. 1 provides a high-level definition of the human receptors, a description of the exposure scenarios assumed, an overview of the methodology including mathematical relationships to determine doses, a listing of recommended parameter values and distributions to use in future PAs, a description of the assumptions applied to ensure the methodology is internally consistent, and a comparison of dose results from previous dose methodologies to this revised approach.

Human Receptor Definitions

In Section 1 of SRR-CWDA-2013-00058, Rev. 1, DOE describes the human receptors considered by the revised dose calculation methodology. DOE evaluates two hypothetical human dose receptors, a member of the public (MOP) and the inadvertent human intruder (IHI), in the revised dose calculation methodology. DOE evaluates exposures that may result from either the use of water from a contaminated well located along a 100-meter boundary surrounding the source of contaminants (i.e., Tank Farms [TFs] or SDF) or from the nearest downgradient stream for the MOP and use of water from a contaminated well at the 1-m

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[1] The FTF PA is documented in SRS-REG-2007-00002, Rev. 1.
[2] The HTF PA is documented in SRR-CWDA-2010-00128, Rev. 1.
[3] The SDF PA is documented in SRR-CWDA-2009-00017, Rev. 0.

boundary surrounding the source terms (i.e., TFs or SDF) or at a well 1-m from a tank or disposal structure for the IHI.

For both the MOP and the IHI, DOE considers a hypothetical reference person in the revised dose calculation methodology, using age- and gender-dependent intake rates for ingestion of water and inhalation of air, rather than assuming adult-specific values. DOE assumes that the hypothetical reference person is typical of the entire population and is established at the median of the national data. Table 1 summarizes the definition of hypothetical human receptors.

Table 1. Definition of Hypothetical Human Receptors

Characteristic	MOP	IHI
Demographic of Receptor	Age- and Gender-Weighted Reference Person	
Location of Receptor	At the 100-meter Boundary -OR- At the nearest downgradient stream	Within the 100-meter Boundary
Behaviors of the Receptor	Median Living Habits	

Note: Adapted from Table 1.1-1 of SRR-CWDA-2013-00058, Rev. 1.

Exposure Scenarios and Pathways

In Section 1 of SRR-CWDA-2013-00058, Rev. 1, DOE describes the exposure scenarios and pathways considered by the revised dose calculation methodology for each of the human receptors. DOE considers two different exposure scenarios for each of its hypothetical human receptors, resulting in a total of four exposure scenarios. DOE considers two scenarios for the MOP receptor: a scenario involving chronic exposures in which the MOP receptor uses water from a contaminated well located at the 100-m boundary from the TFs and the SDF, and a scenario involving chronic exposures in which the MOP receptor uses contaminated water from a location at the nearest downgradient stream from the TFs and SDF[4]. DOE also considers two scenarios for an IHI receptor who drills a well within the 100-m boundary for use of contaminated water: a scenario involving acute exposures and a scenario involving chronic exposures.

For the two scenarios involving the MOP receptor, DOE evaluates a variety of exposure pathways including external, ingestion, and inhalation. The pathways are summarized in Figure 1. DOE evaluates external exposures from contaminated irrigated soils and immersion in contaminated water while showering, swimming, and boating. DOE evaluates exposures resulting from ingestion of contaminated water, soil, and foods. DOE evaluates exposures from inhalation of contaminated irrigation water, dust from irrigated soil, humid air during showering, and saturated air during swimming. The primary difference between the exposure scenarios for the MOP receptor is the source of contaminated water used for drinking, irrigation, and showering. For the MOP at the 100-m boundary, the contaminated water used for drinking and irrigation originates from the well located at the 100-m boundary, while water for swimming, boating, and fish ingestion originate from the streamwater. For the MOP receptor exposure scenario at the nearest downgradient stream, the contaminated water for all pathways originates from water at the location of the nearest downgradient stream, as described earlier.

For the IHI receptor, DOE evaluates scenarios involving both acute and chronic exposures. Figure 1 summarizes the pathways considered for the IHI receptor. For acute exposures, DOE evaluates external exposure to contaminated drill cuttings and exposures resulting from ingestion of soil and inhalation of dust from contaminated drill cuttings. For chronic exposures, DOE evaluates external, ingestion, and inhalation exposures using pathways that are similar to the pathways evaluated for the MOP receptor, which are summarized in the preceding paragraph, with the doses from contamination in well and stream waters supplemented by doses from contaminated drill cuttings that result from the hypothetical inadvertent intrusion. For example, DOE only considers direct exposure to soil contaminated with irrigation water for the MOP receptor; whereas, for the IHI receptor, DOE considers direct exposure to soil contaminated with both irrigation water and drill cuttings.

Dose Calculations

DOE describes in detail the mathematical equations used to represent the exposure pathways and calculate doses for the human receptor scenarios in Sections 3 through 6 of SRR-CWDA-2013-00058, Rev. 1. Section 3 details equations for the MOP at the 100-m

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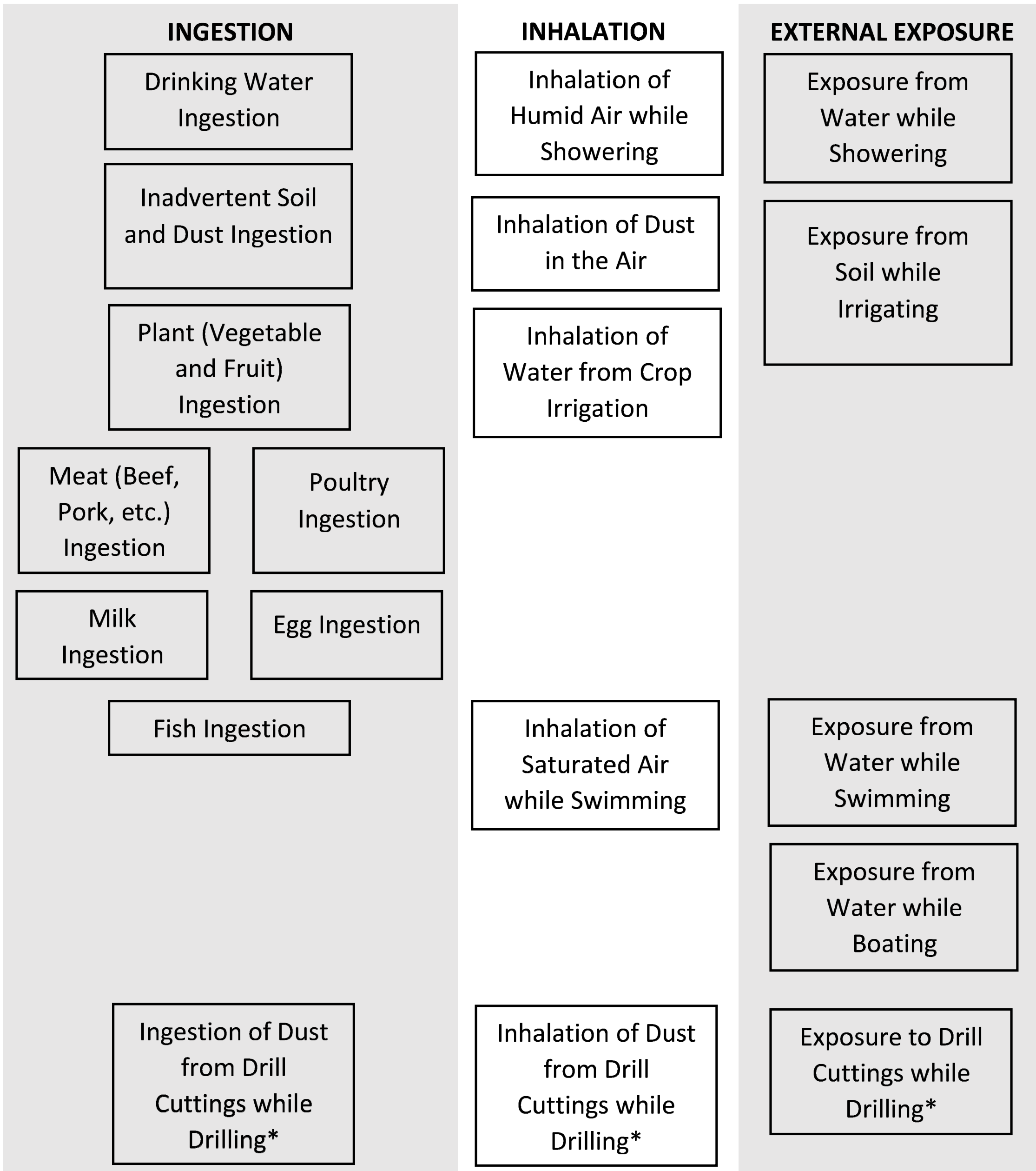
[4] DOE applies a dilution factor for the groundwater from the 100-m boundary to the location at the nearest downgradient stream before the water discharges to the stream, but does not further dilute the contaminated groundwater in the stream.



Notes: Adapted from Figure 1-2 of SRR-CWDA-2013-00058, Rev. 1.
* Pathways related to drill cuttings while drilling only apply to IHI acute scenarios.

Figure 1. Exposure Pathway Overview

boundary. Section 4 details equations for the MOP at the nearest downgradient stream. Section 5 details equations for IHI acute exposure scenario. Section 6 details equations for IHI chronic exposure scenario.

Parameter Values and Distributions

DOE describes the recommended parameter values and distributions in Section 7 of SRR-CWDA-2013-00058, Rev. 1. DOE also describes how the recommended parameter values and distributions were developed. The following sections summarize how DOE developed the recommended parameter values and distributions for dose conversion factors, human and animal consumption rates, fractions of food for humans and animals from contaminated sources, biotic accumulation transfer coefficients, exposure and inhalation parameters, and physical parameters.

Dose Conversion Factors

Table 2 lists the dose coefficients recommended for use in FTF, HTF, and SDF PAs[5].

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[5] DOE's list of recommended dose coefficients in SRR-CWDA-2013-00058, Rev. 1 provides an alternative coefficient for radionuclides where secular equilibrium may exist with selected shorter-lived progeny to simplify the modeling. To develop the alternative dose coefficient, which includes the impact of secular equilibrium with shorter-lived progeny, DOE assumed that the selected progeny are in secular equilibrium with the parent radionuclide. The parent radionuclides (and selected progeny assumed in equilibrium) for which DOE provides additional dose coefficients include:

- Ac-227 (Th-227, Fr-223, Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Tl-207, Po-211)
- Am242m (Am-242, Np-238, Cm-242)
- Am-243 (Np-239)
- Bi-210m (Tl-206)
- Cm-247 (Pu-243)
- Cs-137 (Ba-137m)
- Np-237 (Pa-233)
- Pb-210 (Bi-210, Po-210)
- Pu-244 (U-240, Np-240m)
- Ra-226 (Rn-222, Po-218, Pb-214, At-218, Bi-214, Po-214)
- Ra-228 (Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208)
- Sn-126 (Sb-126m, Sb-126)
- Sr-90 (Y-90)
- Th-229 (Ra-225, Ac-225, Fr-221, At-217, Bi-213, Po-213, Tl-209, Pb-209)
- U-232 (Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, Tl-208)
- U-235 (Th-231)

Table 2. DOE Recommended Dose Coefficients

Nuclide	Internal		External	
	Ingestion†	Inhalation‡	Soil Exposure‡	Water Immersion‡
	(mrem/pCi)		(m^3×mrem)/(pCi×yr)	
Ac-225	$1.94×10^{-04}$	$3.77×10^{-03}$	$3.21×10^{-8}$	$1.47×10^{-07}$
Ac-227*	$2.31×10^{-03}$	$6.00×10^{-01}$	$1.21×10^{-6}$	$4.85×10^{-06}$
Ac-228	$1.90×10^{-06}$	$5.03×10^{-05}$	$2.72×10^{-6}$	$1.01×10^{-05}$
Ag-108m	$1.09×10^{-05}$	$2.59×10^{-05}$	$5.03×10^{-6}$	$1.83×10^{-05}$
Al-26	$1.70×10^{-05}$	$4.85×10^{-05}$	$8.58×10^{-6}$	$3.25×10^{-05}$
Am-241	$8.81×10^{-04}$	$3.63×10^{-01}$	$2.32×10^{-8}$	$1.80×10^{-07}$
Am-242	$1.56×10^{-06}$	$4.96×10^{-05}$	$2.80×10^{-8}$	$1.48×10^{-07}$
Am-242m*	$8.60×10^{-04}$	$3.55×10^{-01}$	$3.61×10^{-8}$	$1.81×10^{-07}$
Am-243*	$8.77×10^{-04}$	$3.61×10^{-01}$	$5.19×10^{-7}$	$2.40×10^{-06}$
Ar-39	0	0	$4.96×10^{-10}$	$1.49×10^{-08}$
At-217	0	0	$6.94×10^{-10}$	$2.70×10^{-09}$
At-218	0	0	$3.34×10^{-11}$	$1.46×10^{-10}$
Ba-133	$9.03×10^{-06}$	$7.62×10^{-06}$	$1.07×10^{-6}$	$4.16×10^{-06}$
Ba-137m	0	0	$1.88×10^{-6}$	$6.81×10^{-06}$
Bi-210	$6.66×10^{-06}$	$4.77×10^{-06}$	$3.35×10^{-9}$	$3.48×10^{-08}$
Bi-210m*	$7.44×10^{-05}$	$2.01×10^{-04}$	$7.70×10^{-7}$	$2.96×10^{-06}$
Bi-211	0	0	$1.40×10^{-7}$	$5.27×10^{-07}$
Bi-212	$1.30×10^{-06}$	$3.81×10^{-05}$	$3.37×10^{-7}$	$1.26×10^{-06}$
Bi-213	$9.92×10^{-07}$	$4.44×10^{-05}$	$3.93×10^{-7}$	$1.47×10^{-06}$
Bi-214	$5.51×10^{-07}$	$3.05×10^{-05}$	$4.76×10^{-6}$	$1.80×10^{-05}$
Bk-249	$4.63×10^{-06}$	$1.63×10^{-03}$	$3.85×10^{-12}$	$6.33×10^{-11}$
C-14	$2.34×10^{-06}$	$8.07×10^{-07}$	$6.91×10^{-12}$	$3.37×10^{-10}$
Ca-41	$1.10×10^{-06}$	$8.47×10^{-07}$	0	0
Cd-113m	$9.51×10^{-05}$	$4.33×10^{-04}$	$5.46×10^{-10}$	$1.24×10^{-08}$
Ce-144	$2.68×10^{-05}$	$1.81×10^{-04}$	$3.91×10^{-8}$	$1.88×10^{-07}$
Cf-249	$1.65×10^{-03}$	$6.59×10^{-01}$	$9.80×10^{-7}$	$3.63×10^{-06}$
Cf-250	$8.21×10^{-04}$	$3.04×10^{-01}$	$3.14×10^{-8}$	$1.21×10^{-07}$
Cf-251	$1.68×10^{-03}$	$6.70×10^{-01}$	$2.83×10^{-7}$	$1.25×10^{-06}$
Cf-252	$5.59×10^{-04}$	$1.64×10^{-01}$	$1.46×10^{-6}$	$5.62×10^{-06}$
Cl-36	$4.59×10^{-06}$	$1.52×10^{-06}$	$1.46×10^{-9}$	$2.27×10^{-08}$
Cm-242	$7.10×10^{-05}$	$1.46×10^{-02}$	$7.93×10^{-11}$	$1.06×10^{-09}$
Cm-243	$6.66×10^{-04}$	$2.65×10^{-01}$	$3.25×10^{-7}$	$1.37×10^{-06}$
Cm-244	$5.59×10^{-04}$	$2.81×10^{-01}$	$1.13×10^{-10}$	$1.08×10^{-09}$
Cm-245	$8.95×10^{-04}$	$3.70×10^{-01}$	$2.18×10^{-7}$	$1.04×10^{-06}$
Cm-246	$8.92×10^{-04}$	$3.70×10^{-01}$	$1.16×10^{-8}$	$4.52×10^{-08}$
Cm-247*	$8.22×10^{-04}$	$3.39×10^{-01}$	$9.99×10^{-7}$	$3.76×10^{-06}$
Cm-248	$3.34×10^{-03}$	$1.36×10^{+00}$	$4.19×10^{-6}$	$1.62×10^{-05}$
Co-60	$2.03×10^{-05}$	$2.23×10^{-05}$	$8.07×10^{-6}$	$3.01×10^{-05}$
Cs-134	$6.92×10^{-05}$	$2.43×10^{-05}$	$4.92×10^{-6}$	$1.79×10^{-05}$

- U-238 (Th-234, Pa-234m, Pa-234)

The values reported for these radionuclides in Table 2 are the alternative values that include the impact of secular equilibrium with shorter-lived progeny.

Table 2. DOE Recommended Dose Coefficients (Continued)

Nuclide	Internal		External	
	Ingestion†	Inhalation†	Soil Exposure‡	Water Immersion‡
	(mrem/pCi)		(m^3×mrem)/(pCi×yr)	
Cs-135	9.77×10^{-6}	3.38×10^{-06}	4.88×10^{-11}	2.77×10^{-09}
Cs-137*	4.92×10^{-05}	1.70×10^{-05}	1.78×10^{-6}	6.44×10^{-06}
Eu-152	6.44×10^{-06}	3.67×10^{-04}	3.63×10^{-6}	1.37×10^{-05}
Eu-154	9.66×10^{-06}	4.26×10^{-04}	3.92×10^{-6}	1.46×10^{-05}
Eu-155	1.67×10^{-06}	5.11×10^{-05}	1.02×10^{-7}	5.69×10^{-07}
Fr-221	0	0	8.01×10^{-8}	3.21×10^{-07}
Fr-223	1.20×10^{-05}	4.18×10^{-06}	1.04×10^{-7}	5.31×10^{-7}
Gd-152	1.97×10^{-04}	7.44×10^{-02}	0	0
H-3	7.77×10^{-08}	2.47×10^{-08}	0	0
I-129	4.48×10^{-04}	1.50×10^{-04}	6.06×10^{-09}	7.80×10^{-08}
K-40	3.04×10^{-05}	9.55×10^{-06}	5.14×10^{-07}	1.96×10^{-06}
Kr-85	0	0	7.79×10^{-09}	4.38×10^{-08}
Lu-174	1.42×10^{-06}	3.00×10^{-05}	2.55×10^{-07}	1.15×10^{-06}
Mo-93	1.15×10^{-05}	3.65×10^{-06}	2.56×10^{-10}	4.66×10^{-09}
Mo-93m	5.44×10^{-07}	4.63×10^{-07}	7.39×10^{-06}	2.76×10^{-05}
Na-22	1.44×10^{-05}	5.59×10^{-06}	6.97×10^{-06}	2.57×10^{-05}
Nb-93m	6.59×10^{-07}	1.03×10^{-06}	4.57×10^{-11}	8.33×10^{-10}
Nb-94	8.25×10^{-06}	2.46×10^{-05}	4.95×10^{-06}	1.81×10^{-05}
Ni-59	2.95×10^{-07}	7.47×10^{-07}	4.83×10^{-11}	1.75×10^{-10}
Ni-63	7.33×10^{-07}	1.84×10^{-06}	0	0
Np-237*	4.67×10^{-04}	1.87×10^{-01}	6.44×10^{-07}	2.60×10^{-06}
Np-238	4.44×10^{-06}	1.32×10^{-05}	1.86×10^{-06}	6.87×10^{-06}
Np-239	4.11×10^{-06}	8.33×10^{-07}	4.39×10^{-07}	1.89×10^{-06}
Np-240	3.55×10^{-07}	1.46×10^{-07}	3.22×10^{-06}	1.20×10^{-05}
Np-240m	0	0	1.01×10^{-06}	3.74×10^{-06}
Pa-231	2.07×10^{-03}	8.77×10^{-01}	9.49×10^{-08}	3.71×10^{-07}
Pa-233	4.88×10^{-06}	5.29×10^{-06}	6.02×10^{-07}	2.37×10^{-06}
Pa-234	2.06×10^{-06}	6.03×10^{-07}	4.53×10^{-06}	1.69×10^{-05}
Pa-234m	0	0	6.96×10^{-08}	2.86×10^{-07}
Pb-209	2.76×10^{-07}	7.73×10^{-08}	4.64×10^{-10}	1.31×10^{-08}
Pb-210*	1.03×10^{-02}	6.57×10^{-03}	4.69×10^{-09}	4.76×10^{-08}
Pb-211	9.69×10^{-07}	1.62×10^{-05}	2.06×10^{-07}	7.80×10^{-07}
Pb-212	3.81×10^{-05}	8.07×10^{-05}	3.78×10^{-07}	1.56×10^{-06}
Pb-214	7.36×10^{-07}	1.24×10^{-05}	7.34×10^{-07}	2.81×10^{-06}
Pd-107	1.96×10^{-07}	1.19×10^{-07}	0	0
Pm-147	1.34×10^{-06}	2.95×10^{-05}	2.69×10^{-11}	1.13×10^{-09}
Po-210	6.48×10^{-03}	2.83×10^{-03}	3.08×10^{-11}	1.13×10^{-10}
Po-211	0	0	2.58×10^{-08}	9.43×10^{-08}
Po-212	0	0	0	0
Po-213	0	0	1.19×10^{-10}	4.33×10^{-10}
Po-214	0	0	7.34×10^{-07}	9.61×10^{-10}
Po-215	0	0	5.42×10^{-10}	1.98×10^{-09}
Po-216	0	0	4.86×10^{-11}	1.77×10^{-10}
Po-218	0	0	5.77×10^{-15}	3.34×10^{-13}
Pr-144	2.52×10^{-07}	4.70×10^{-08}	1.32×10^{-07}	5.20×10^{-07}
Pt-193	1.82×10^{-07}	1.06×10^{-07}	2.73×10^{-12}	7.67×10^{-11}

Table 2. DOE Recommended Dose Coefficients (Continued)

Nuclide	Internal		External	
	Ingestion†	Inhalation†	Soil Exposure‡	Water Immersion‡
	(mrem/pCi)		(m^3×mrem)/(pCi×yr)	
Pu-238	9.73×10^{-04}	4.07×10^{-01}	6.94×10^{-11}	9.12×10^{-10}
Pu-239	1.07×10^{-03}	4.48×10^{-01}	1.67×10^{-10}	9.94×10^{-10}
Pu-240	1.07×10^{-03}	4.48×10^{-01}	7.01×10^{-11}	8.94×10^{-10}
Pu-241	1.93×10^{-05}	8.51×10^{-03}	3.26×10^{-12}	1.60×10^{-11}
Pu-242	1.01×10^{-03}	4.26×10^{-01}	2.99×10^{-10}	1.67×10^{-09}
Pu-243	4.33×10^{-07}	1.39×10^{-07}	4.40×10^{-08}	2.43×10^{-07}
Pu-244*	1.02×10^{-03}	4.18×10^{-01}	1.08×10^{-06}	4.03×10^{-06}
Ra-223	8.03×10^{-04}	6.77×10^{-04}	3.47×10^{-07}	1.48×10^{-06}
Ra-224	4.66×10^{-04}	3.96×10^{-04}	2.97×10^{-08}	1.15×10^{-07}
Ra-225	8.81×10^{-04}	7.40×10^{-04}	5.57×10^{-09}	6.34×10^{-08}
Ra-226*	1.68×10^{-03}	1.77×10^{-03}	5.52×10^{-06}	2.09×10^{-05}
Ra-228*	6.86×10^{-03}	1.33×10^{-01}	7.34×10^{-06}	2.84×10^{-05}
Rb-87	7.59×10^{-06}	2.39×10^{-06}	8.41×10^{-11}	4.55×10^{-09}
Re-188	7.10×10^{-06}	2.22×10^{-06}	1.89×10^{-07}	7.71×10^{-07}
Rh-106	0	0	7.01×10^{-07}	2.57×10^{-06}
Rn-219	0	0	1.74×10^{-07}	6.54×10^{-07}
Rn-220	0	0	1.96×10^{-09}	7.12×10^{-09}
Ru-106	3.55×10^{-05}	3.58×10^{-05}	0	0
S-35	6.44×10^{-07}	2.35×10^{-07}	7.62×10^{-12}	3.97×10^{-10}
Sb-125	5.44×10^{-06}	6.03×10^{-06}	1.31×10^{-06}	4.81×10^{-06}
Sb-126	1.29×10^{-05}	4.81×10^{-06}	8.69×10^{-06}	3.16×10^{-05}
Sb-126m	1.85×10^{-07}	5.59×10^{-08}	4.87×10^{-06}	1.77×10^{-05}
Sc-46	6.96×10^{-06}	2.81×10^{-05}	6.42×10^{-06}	2.37×10^{-05}
Se-79	1.73×10^{-05}	6.22×10^{-06}	7.97×10^{-12}	3.95×10^{-10}
Sm-147	2.37×10^{-04}	9.03×10^{-02}	0	0
Sm-151	5.00×10^{-07}	3.64×10^{-05}	4.53×10^{-13}	7.24×10^{-12}
Sn-121	1.17×10^{-06}	2.83×10^{-07}	1.10×10^{-10}	5.09×10^{-09}
Sn-121m	1.96×10^{-06}	3.62×10^{-06}	9.04×10^{-10}	1.31×10^{-08}
Sn-126*	2.56×10^{-05}	4.99×10^{-05}	6.17×10^{-06}	2.27×10^{-05}
Sr-90*	1.47×10^{-04}	1.05×10^{-04}	2.46×10^{-08}	1.28×10^{-07}
Tc-99	3.33×10^{-06}	1.34×10^{-06}	6.88×10^{-11}	3.67×10^{-09}
Te-125m	4.51×10^{-06}	2.38×10^{-06}	6.95×10^{-09}	9.08×10^{-08}
Th-227	5.44×10^{-05}	3.20×10^{-03}	3.36×10^{-07}	1.34×10^{-06}
Th-228	4.29×10^{-04}	1.27×10^{-01}	4.45×10^{-09}	2.15×10^{-08}
Th-229*	3.33×10^{-03}	9.26×10^{-01}	8.31×10^{-07}	3.42×10^{-06}
Th-230	9.36×10^{-04}	3.85×10^{-01}	6.82×10^{-10}	3.99×10^{-09}
Th-231	1.71×10^{-06}	3.64×10^{-07}	2.03×10^{-08}	1.19×10^{-07}
Th-232	1.03×10^{-03}	4.26×10^{-01}	2.98×10^{-10}	2.10×10^{-09}
Th-234	1.73×10^{-05}	1.23×10^{-05}	1.45×10^{-08}	8.43×10^{-08}
Tl-207	0	0	1.37×10^{-08}	7.59×10^{-08}
Tl-208	0	0	1.08×10^{-05}	4.25×10^{-05}
Tl-209	0	0	6.76×10^{-06}	2.57×10^{-5}
U-232*	2.43×10^{-03}	1.44×10^{-01}	4.62×10^{-06}	1.82×10^{-05}
U-233	2.23×10^{-04}	2.36×10^{-03}	5.56×10^{-10}	2.74×10^{-09}
U-234	2.15×10^{-04}	2.28×10^{-03}	2.15×10^{-10}	1.63×10^{-09}
U-235*	2.05×10^{-04}	2.12×10^{-03}	4.47×10^{-07}	1.88×10^{-06}

Table 2. DOE Recommended Dose Coefficients (Continued)

Nuclide	Internal		External	
	Ingestion†	Inhalation†	Soil Exposure‡	Water Immersion‡
	(mrem/pCi)		(m³×mrem)/(pCi×yr)	
U-236	2.02×10^{-04}	2.14×10^{-03}	1.10×10^{-10}	1.01×10^{-09}
U-238*	2.13×10^{-04}	2.06×10^{-03}	4.61×10^{-06}	1.73×10^{-05}
U-240	5.55×10^{-06}	9.25×10^{-07}	9.25×10^{-09}	5.02×10^{-08}
W-181	4.18×10^{-07}	1.35×10^{-07}	4.00×10^{-08}	3.07×10^{-07}
W-185	2.24×10^{-06}	5.48×10^{-07}	2.29×10^{-10}	6.62×10^{-09}
W-188	1.05×10^{-05}	2.68×10^{-06}	5.29×10^{-09}	2.43×10^{-08}
Y-90	1.37×10^{-05}	2.59×10^{-06}	2.42×10^{-08}	1.15×10^{-07}
Zr-93	3.70×10^{-06}	8.14×10^{-05}	0	7.88×10^{-14}

Note: Adapted from Table 7.1-1 of SRR-CWDA-2013-00058, Rev. 1.

* Value shows the sum of a parent radionuclide plus daughter products assumed to be at secular equilibrium.
† Values for ingestion and inhalation dose coefficients for Reference Person fromTables A-1and A-2, respectively, of DOE-STD-1196-2011. The values reported in this table are converted from units of Sv/Bq, as reported in DOE-STD-1196-2011 to mrem/pCi.
‡ Values for soil exposure, assuming 0.15-m depth, and water immersion dose coefficients calculated with software associated with the U.S. EPA's FGRs 12 and 13 (EPA-402-R-93-081; EPA-402-R-99-001) and a revised input data set.

The recommended dose coefficients for the ingestion and inhalation exposure pathways come from Tables A-1 and A-2 of DOE-STD-1196-2011, respectively. In DOE-STD-1196-2011, DOE establishes Derived Concentration Standards (DCS), which are quantities that represent the concentration of a given radionuclide in either water or air that results in a MOP receiving 1 millisievert (mSv) [100 millirem (mrem)] effective dose following continuous exposure for one year for ingestion of water and inhalation. DOE computes the DCS values using effective dose coefficients for reference age groups that were calculated in a manner similar to ICRP Publication 72 (ICRP, 1995) and the U.S. Environmental Protection Agency's (U.S. EPA's) Federal Guidance Report (FGR) 13 (EPA, 1999). However, DOE, uses more recent age- and gender-specific physiological parameters for members of the public that are set forth in ICRP Publication 89 (ICRP, 2002) and nuclear decay data of ICRP Publication 107 (ICRP, 2008). The DOE derives the DCS by weighting the effective dose coefficients calculated for a reference person[6] of each reference age group of the public by age- and gender- dependent intake rates for ingestion of water and inhalation of air. The reference age groups of the public are represented by six age groups (Newborn, 1-year, 5-year, 10-year, 15-year, and Adult).

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[6] The reference person gender-averages tissue weighting factors.

Specifically, DOE weights the effective dose coefficients for each age group by the sum of the fractional representation of each gender in the U.S. population and their intake of the radionuclide through inhalation of air and ingestion of water. Table 3 lists the population fractions and daily intakes of water and air used to weight the age-specific effective dose coefficients.

The recommended dose coefficients for soil and water external exposure pathways come from calculations involving software associated with the U.S. EPA's FGRs 12 and 13 (EPA-402-R-93-081; EPA-402-R-99-001) and a revised input data set [7].

Table 3. DOE Population and Usage Data for Derived Concentration Standards

Reference Age Group	Age, x	Population Fraction*		Daily Intake			
				Air† (m^3)		Water‡ (L)	
	yr	Male	Female	Male	Female	Male	Female
Newborn	**0 ≤ x < 1**	0.00693	0.00660	4.15	4.15	1.07	1.07
1-yr	**1 ≤ x < 3**	0.01383	0.01321	5.89	5.89	1.12	1.12
5-yr	**3 ≤ x < 7**	0.02864	0.02731	9.00	9.08	1.27	1.27
10-yr	**7 ≤ x < 12**	0.03814	0.03632	15.2	15.0	1.50	1.50
15-yr	**12 ≤ x < 17**	0.03672	0.03482	20.0	15.8§	2.02	1.52§
Adult	**x ≥ 17**	0.36630	0.39118	22.2	17.7§	2.29	1.71§

Note: Adapted from Table 3 of DOE-STD-1196-2011.
* Population fraction based on U.S. Census for the year 2000.
† Daily air intake based on ICRP Publication 89 (ICRP, 2002).
‡ Daily water intake based on Roseberry and Burnmaster (1992).
§ DOE assumes that female daily intake for x ≥ 12 yr is 75-percent of male daily intake

[7] Computations were performed using the DCFPAK Version 3.02 software (Dose Coefficient File and Package, which is available from the U.S. EPA (https://www.epa.gov/radiation/tools-calculating-radiation-dose-and-risk#tab-3) and allows electronic access to nuclear decay data and dose and risk coefficients for exposure to radionuclides. The input data set used to determine external dose coefficients for SRS includes data files titled FGR12III2.DAT and FGR12III6.DAT, which contain external dose rate coefficients based on the nuclear decay data of ICRP Publication 107 (ICRP, 2008) for each of 1,252 radionuclides for the water submersion and standing on soil contaminated to 15 cm, respectively. The external dose coefficients are based on the models described in FGR 12.

Human Uptake Parameters

Table 4 summarizes the values and distributions that DOE recommends for human consumption parameters in SRS PAs[8]. DOE develops the values for human consumption from parameters from the 2011 U.S. EPA Exposure Factors Handbook (EPA/600/R-09/052F). Generally, DOE recommends values for the deterministic modeling that corresponded to values the “All Ages” or “All Individuals” groups from data presented in EPA/600/R-09/052F. DOE considers all the data presented in EPA/600/R-09/052F for these categories for each of the consumption parameters and generally recommends the largest mean or median value presented for the deterministic modeling. DOE’s recommended consumption parameter values for the deterministic modeling are discussed for each uptake parameter below.

To develop the probabilistic distributions, DOE recommends parameter values for multiplier distributions that are fit to the percentile data presented in EPA/600/R-09/052F. DOE normalizes the percentiles from the survey data to the mean or median of the survey data and, using trial and error, fits a distribution to the normalized percentiles as described for each parameter below. DOE then truncates each distribution at the 10th and 90th percentiles of the respective distribution to limit the sampled values to those DOE considers are representative of typical and reasonable human behavior.

[8] Note that the consumption data reported in Table 3, which was used to develop DCS, is distinct from the consumption data developed for use directly in the SRS PAs, which is reported in Table 4. The DCS developed from the consumption data reported in Table 3 are used as dose coefficients in the dose methodology for SRS PAs, but the consumption data is not used directly in SRS PAs. Rather the consumption data reported in Table 4 is used directly in SRS PAs.

Table 4. DOE Recommended Human Uptake Parameter Values

Parameter	Unit	Deterministic Value	Probabilistic Multiplier				
			Distribution	Mean/ Mode	SD	Min.	Max.
Rate of Contaminated Water Consumption	L/yr	340‡	Gamma	1.2	0.8	0.26	2.3
Rate of Soil and Dust Consumption	kg/yr	3.65×10^{-2}	Triangular	1.0	N/A	0.5	2.0
Rate of Produce Consumption	kg/yr	132	Log-Normal	0.9†	2.6†	0.2	3.07
Rate of Meat Consumption	kg/yr	61.4	Gamma	1.0	0.69	0.29	1.88
Rate of Milk Consumption	kg/yr*	86	Gamma	1.0	0.94	0.16	2.16
Rate of Poultry Consumption	kg/yr	10.6	N/A	N/A	N/A	N/A	N/A
Rate of Egg Consumption	kg/yr	7.3	N/A	N/A	N/A	N/A	N/A
Rate of Fish Consumption	kg/yr	5.6	Log-Normal	1.0†	2.3†	0.33	2.93
Human Breathing Rate	m^3/yr	5,844	Gamma	1.0	0.23	0.77	1.27

Note: Adapted from Table 7.2-1 of SRR-CWDA-2013-00058, Rev. 1.
* For use in dose calculations, rate of milk consumption values must be converted to L/yr by dividing by density of the milk, which is assumed to be 1.03 L/kg.
† Use geometric mean and geometric standard deviation for these parameter values.
‡ Rate of contaminated water consumption accounts for total water consumption and the fraction of total water consumed from a contaminated source.

SD: Standard Deviation
Min.: Minimum Value
Max.: Maximum Value

Water Consumption

Unlike other recommended deterministic values for human consumption parameters, DOE's recommended deterministic value for rate of water consumption directly accounts for the fraction of water consumed that is contaminated. To develop a recommended value for the rate of water consumption that is contaminated, DOE assumes that all water ingested will be contaminated except for the fraction of water consumed from bottled sources. Equation 1 summarizes DOE's estimation of the recommended value for the rate of water consumption.

$$U_{H_2O} = \tilde{u}_{H_2O,A} \times \left(1 - \frac{\bar{u}_{H_2O,B}}{\bar{u}_{H_2O,A}}\right) \qquad \textbf{Eqn. 1}$$

$\tilde{u}_{H_2O,A}$ ≡ Median per capita estimate for "All Ages" of combined direct and indirect water ingestion from all sources; Table 3-26 of EPA/600/R-09/052F.

$\bar{u}_{H_2O,A}$ ≡ Mean per capita estimate for "All Ages" of combined direct and indirect water ingestion from all sources; Table 3-26 of EPA/600/R-09/052F.

$\bar{u}_{H_2O,B}$ ≡ Mean per capita estimate for "All Ages" of combined direct water ingestion from bottled water; Table 3-24 of EPA/600/R-09/052F.

EPA/600/R-09/052F defines direct water as water ingested daily as beverage, and indirect water as water added in the preparation of food or beverages. DOE used the ratio of mean, rather than median, per capita bottle-to-all sources consumption because less than 50-percent of those surveyed reported drinking bottled water for the survey.

DOE developed the probabilistic distribution for the contaminated water consumption rate multiplier by scaling each water intake percentile value from Table 3-26 of EPA/600/R-09/052F for the "All Adults" group to the ratio of bottled water to all-sources water (e.g., approximately 0.774), which is calculated in Equation 1 above. The scaled percentiles were then normalized to the scaled median value for the "All Adults" group from Table 3-26 of EPA/600/R-09/052F. Through trial and error, DOE found a gamma distribution with the recommended distribution statistic values that provided a close match to the scaled and normalized EPA percentile values, limited to percentiles from the 10th-percentile to the 90th-percentile from Table 3-26.

Soil and Dust Consumption

DOE annualized the general population central tendency daily soil and dust ingestion rate for a child from Table 5-1 of EPA/600/R-09/052F to develop the recommended value for deterministic modeling. DOE selected the ingestion rate for a child because it was larger than the adult ingestion rate. To develop the recommended values for the probabilistic distribution, DOE assumed a triangular distribution with the minimum set at one-half and the maximum value set at twice the recommended deterministic rate.

Produce Consumption

DOE's recommended deterministic value for rate of produce consumption accounts for both fruits and vegetables. To develop the recommended value, DOE annualized the sum of the mean daily total fruit and vegetable intakes for "All Ages" from Table 9-8 of EPA/600/R-09/052F for 1995, which were the largest values reported for "All Ages".

DOE developed the recommended probabilistic distribution parameter values for the produce consumption rate based on consumers of fruits and vegetables rather than the entire population (i.e., both consumers and non-consumers) using survey statistics from Table 9-15 of EPA/600/R-09/052F. DOE normalized the sum of each percentile for the "Whole Population" group of consumers by the sum of the medians for both "Fruits" and "Vegetables" from Table 9-15. Through trial and error, DOE found a log-normal distribution with the recommended distribution statistic values that provided a close match to the normalized EPA percentile values and truncated the distribution at the 10^{th} and 90^{th} percentiles.

Meat and Milk Consumption

To develop the recommended deterministic value for the rate of meat consumption, DOE annualizes the mean per capita daily meat intake for "All Ages" from Table 11-7 of EPA/600/R-09/052F for 1977-1978. DOE includes consumption of beef, pork, lamb, veal, game, frankfurters, sausages, luncheon meats, spreads, and meat mixtures, which include mixtures containing meat, poultry, or fish as a main ingredient. The data presented for 1977-1978 results in a greater intake of meat than data presented from later surveys.

To develop the recommended deterministic value for the rate of milk consumption, DOE annualizes the mean per capita total fluid milk daily intake for "All Individuals" from Table 11-12 of EPA/600/R-09/052F for 1995, which is the largest value reported for "All Individuals". DOE converts the total fluid milk daily intake to volumetric intake based on an assumed milk density of 1.03 kg/L[3].

DOE developed the recommended probabilistic distribution values for meat and milk consumption rates based on consumers of meat and milk rather than the entire population using survey statistics from Table 11-4 of EPA/600/R-09/052F. DOE reportedly normalized each percentile for the "Whole Population" group by the respective mean for both "Total Meat" and "Total Dairy Products" from Table 11-4. Through trial and error, DOE found a gamma distribution with the recommended distribution statistic values that provided a close match to the normalized EPA percentile values and truncated the distribution at the 10^{th} and 90^{th} percentiles.

Poultry and Egg Consumption

To develop the recommended deterministic value for the rate of poultry consumption, DOE annualizes the mean per capita daily total poultry intake for "All Individuals" from Table 11-9 of EPA/600/R-09/052F for 1994, which is the largest value reported for "All Individuals". To develop the recommended deterministic value for the rate of egg consumption, DOE annualizes the mean per capita daily egg intake for "All Individuals" from Table 11-11 of EPA/600/R-09/052F for 1987-1988, which is the largest value reported for "All Individuals".

DOE does not recommend probabilistic distribution values for poultry and egg consumption rates because DOE considers the dose contribution from poultry and egg consumption is considered small relative to the other ingestion pathways.

Fish Consumption

To develop the recommended deterministic value for the rate of fish consumption, DOE averages the mean per capita intake of finfish for adults 20 to 49 years of age and 50 years or more that are reported in Table 10-7 of EPA/600/R-09/052F and normalizes by the mean adult body mass, assuming 80 kg from Table 8-1 of EPA/600/R-09/052F. Because Table 10-13 of EPA/600/R-09/052F reports that residents of the South Atlantic region of the U.S. have a higher per capita consumption rate compared to all fish consumers, DOE increases the averaged mean per capita intake of finfish by 10-percent to account for the regional variability and recommend value for the fish consumption rate.

DOE developed the recommended probabilistic distribution values for the fish consumption rate based on consumers of fish rather than the entire population using survey statistics from on Table 10-23 of EPA/600/R-09/052F. DOE reportedly normalized the percentiles for "All Adult Fish Consumers" by the geometric mean. Through trial and error, DOE found a log-normal distribution with the recommended distribution statistic values that provided a close match to the normalized EPA percentile values and truncated the distribution at the 10^{th} and 90^{th} percentiles.

Breathing Rate

To develop the recommended deterministic value for the human breathing rate, DOE annualized the mean daily inhalation rate for males and females combined from Table 6-1 of EPA/600/R-09/052F for age group 31 to < 41, which has the highest reported rate for adults. DOE developed the recommended probabilistic distribution values for the breathing rate based on the distributions presented in Tables 6-14 (for males) and 6-15 (for females) of

EPA/600/R-09/052F. DOE averaged all the age groups and assumed a population distribution of 48% male and 52% female to develop an age- and gender-weighted cumulative probability distribution. Through trial and error, DOE found a gamma distribution with the recommended distribution statistic values that provided a close match to the weighted EPA percentile values and truncated the distribution at the 10th and 90th percentiles.

Animal and Livestock Uptake Parameters

Table 5 summarizes values and distributions that DOE recommends for livestock consumption of water and fodder. DOE develops the recommended deterministic values for beef and milk cow consumption of fodder and water by annualizing the consumption rates from WSRC-RP-91-17 and Hamby (1992) and the probabilistic values by annualizing the minimum and maximum consumption rates from Table 4-1 of WSRC-STI-2007-00004, Rev. 4. DOE develops the recommended deterministic values for poultry and egg consumption of water, fodder, and soil by annualizing the consumption rates from Table A-1 of Simpkins, et al. (2008; ML083190829). DOE does not develop probabilistic distributions for poultry and egg consumption of water, fodder, or soil because DOE assumes ingestion of poultry and eggs will have a minor impact on dose, relative to meat and milk ingestion pathways.

Table 5. DOE Recommended Animal and Livestock Uptake Parameter Values

Parameter	Unit	Deterministic Value	Probabilistic Multiplier			
			Distribution	Mode	Min.	Max.
Consumption of Water by Terrestrial Livestock	L/yr	10,200	Triangular	1.0	1.0	1.8
Consumption of Fodder by Terrestrial Livestock	kg/yr	13,100	Triangular	1.0	0.75	1.4
Consumption of Water by Milk Cows	L/yr	18,300	Triangular	1.0	1.0	1.2
Consumption of Fodder by Milk Cows	kg/yr	19,000	Triangular	1.0	0.69	1.1
Consumption of Water by Poultry	L/yr*	110	N/A	N/A	N/A	N/A
Consumption of Fodder by Poultry	kg/yr	36.5	N/A	N/A	N/A	N/A
Consumption of Soil by Poultry	kg/yr	3.65	N/A	N/A	N/A	N/A
Consumption of Water by Egg-Producers	L/yr	110	N/A	N/A	N/A	N/A
Consumption of Fodder by Egg-Producers	kg/yr	36.5	N/A	N/A	N/A	N/A
Consumption of Soil by Egg-Producers	kg/yr	3.65	N/A	N/A	N/A	N/A

Note: Adapted from Table 7.2-2 of SRR-CWDA-2013-00058, Rev. 1.
Min.: Minimum Value
Max.: Maximum Value
N/A: Not Applicable

Fractions of Food from Contaminated Sources

Table 6 summarizes the values and distributions that DOE recommends for the fraction of food and drink consumption that is home-produced. DOE developed these values from Table 13-68 of EPA/600/R-09/052F using the total population group, except for the fraction of consumed water from a contaminated source, which is included in the consumption rate of water. To develop a probabilistic distribution, DOE assumed that the maximum of the distribution is double the recommended value and the minimum is half the recommended value.

Table 6. DOE Recommended Fractions of Food Produced Locally

Parameter	Distribution	Mode*	Min.	Max.
Fraction of Consumed Water from Contaminated Source†	Triangular	N/A	N/A	N/A
Fraction of Total Produce Grown at Home	Triangular	0.068	0.034	0.136
Fraction of Total Terrestrial Livestock Produced at Home	Triangular	0.024	0.012	0.048
Fraction of Total Milk Produced at Home	Triangular	0.012	0.006	0.024
Fraction of Total Poultry Produced at Home	Triangular	0.011	0.0055	0.022
Fraction of Total Eggs Produced at Home	Triangular	0.014	0.007	0.028
Fraction of Households that Fish	Triangular	0.094	0.047	0.188

Note: Adapted from Table 7.6-1 of SRR-CWDA-2013-00058, Rev. 1.
* Recommended value for deterministic modeling
† Local fraction for water consumption has already been incorporated into water consumption parameter shown in Table 2

Min.: Minimum
Max.: Maximum
N/A: Not Applicable

Table 7 summarizes the values and distributions that DOE recommends for the fractions of fodder and soil that livestock consume that is contaminated. DOE developed the deterministic beef and milk cow fractions from Hamby (1992), and the probabilistic distribution parameters from Table 4-1 of WSRC-STI-2007-00004, Rev. 4, but the basis for the values in WSRC-STI-2007-00004, Rev. 4 is unclear. DOE does not recommend values for the fraction of water consumed by livestock and animals that is contaminated because the methodology assumes that all water consumed by animals and livestock is contaminated. Similarly, DOE assumes that all fodder and soil consumed by poultry and egg is contaminated, and recommends that the deterministic value be set to unity to reflect this assumption.

Table 7. DOE Recommended Animal and Livestock Uptake Fractions

Parameter	Deterministic Value	Probabilistic Multiplier			
		Distribution	Mode	Min.	Max.
Fraction of Fodder (Consumed by Terrestrial Livestock) that is Contaminated	0.75	Triangular	1.0	0.67	1.33
Fraction of Fodder (Consumed by Milk-Producing Livestock) that is Contaminated	0.56	Triangular	1.0	0.89	1.8
Fraction of Fodder (Consumed by Poultry) that is Contaminated	1.0	N/A	N/A	N/A	N/A
Fraction of Soil (Consumed by Poultry) that is Contaminated	1.0	N/A	N/A	N/A	N/A
Fraction of Fodder (Consumed by Egg-Producers) that is Contaminated	1.0	N/A	N/A	N/A	N/A
Fraction of Soil (Consumed by Egg-Producers) that is Contaminated	1.0	N/A	N/A	N/A	N/A

Note: Adapted from Table 7.2-3 of SRR-CWDA-2013-00058, Rev. 1.
Min.: Minimum Value
Max.: Maximum Value
N/A: Not Applicable

<u>Transfer Coefficients for Biotic Accumulation</u>

Table 8 summarizes the values recommended by DOE for transfer coefficients for soil-to-plant, fodder-to-meat, fodder-to-milk, fodder-to-poultry, fodder-to-egg, and water-to-fish for the deterministic modeling and the recommended distribution values for a multiplier for the probabilistic modeling. DOE develops the recommended values for deterministic modeling by selecting transfer coefficient values from a hierarchy of references: (1^{st}) International Atomic Energy Agency's (IAEA) Technical Report Series No. 472 (IAEA-TRS-472), (2^{nd}) Pacific Northwest National Laboratory's Compendium of Transfer Factors (PNNL-13421), (3^{rd}) an Oak Ridge National Laboratory Compendium of Parameters for Transport through Agriculture (ORNL-5786), (4^{th}) an NRC Parameter Analysis for Translating Residual Radioactivity to Dose (NUREG/CR--5512, Vol. 3), (5^{th}) an SRS Human Health Parameter Update for PAs (WSRC-STI-2007-00004, Rev, 4), and (6^{th}) the HTF PA, Rev. 1 (SRR-CWDA-2010-00128,

Table 8. DOE Recommended Biotic Accumulation Transfer Coefficients

Element	Soil-to-Plant	Fodder-to- Meat	Fodder-to- Milk	Fodder-to- Poultry	Fodder-to- Egg	Water-to-Fish
Ac	6.00×10^{-05}	1.10×10^{-06}	5.48×10^{-08}	1.64×10^{-05}	1.10×10^{-05}	$2.50\times10^{+01}$
Ag	1.25×10^{-04}	8.21×10^{-06}	4.33×10^{-06}	5.48×10^{-03}	1.37×10^{-03}	$1.10\times10^{+02}$
Al	2.90×10^{-04}	4.11×10^{-06}	5.64×10^{-07}	1.00×10^{-20}	1.00×10^{-20}	$5.10\times10^{+01}$
Am	7.74×10^{-05}	1.37×10^{-06}	1.15×10^{-09}	1.64×10^{-05}	8.21×10^{-06}	$2.40\times10^{+02}$
Ar	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
As	2.52×10^{-03}	5.48×10^{-06}	1.64×10^{-07}	2.27×10^{-03}	7.12×10^{-04}	$3.30\times10^{+02}$
At	7.00×10^{-02}	2.74×10^{-05}	2.82×10^{-05}	1.00×10^{-20}	1.00×10^{-20}	$1.50\times10^{+01}$
Au	2.66×10^{-03}	1.37×10^{-05}	1.51×10^{-08}	2.74×10^{-03}	1.37×10^{-03}	$2.40\times10^{+02}$
B	5.60×10^{-01}	2.19×10^{-06}	4.23×10^{-06}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
Ba	9.63×10^{-02}	3.83×10^{-07}	4.38×10^{-07}	5.20×10^{-05}	2.38×10^{-03}	$1.20\times10^{+00}$
Be	6.29×10^{-04}	2.74×10^{-06}	2.27×10^{-09}	1.10×10^{-03}	5.48×10^{-05}	$1.00\times10^{+02}$
Bi	9.63×10^{-02}	1.10×10^{-06}	1.37×10^{-06}	2.68×10^{-04}	7.12×10^{-04}	$1.50\times10^{+01}$
Bk	2.40×10^{-04}	6.84×10^{-08}	5.48×10^{-09}	1.00×10^{-20}	1.00×10^{-20}	$2.50\times10^{+01}$
Br	2.89×10^{-01}	6.84×10^{-05}	5.48×10^{-05}	1.10×10^{-05}	4.38×10^{-3}	$9.10\times10^{+01}$
C	1.35×10^{-01}	8.49×10^{-05}	3.29×10^{-05}	1.00×10^{-20}	1.00×10^{-20}	$3.00\times10^{+00}$
Ca	$4.14\times10^{+00}$	3.56×10^{-05}	2.74×10^{-05}	1.20×10^{-04}	1.20×10^{-03}	$1.20\times10^{+01}$
Cd	1.74×10^{-01}	1.59×10^{-05}	5.20×10^{-07}	4.65×10^{-03}	2.74×10^{-04}	$2.00\times10^{+02}$
Ce	2.28×10^{-03}	5.48×10^{-08}	5.48×10^{-08}	5.48×10^{-06}	8.49×10^{-06}	$2.50\times10^{+01}$
Cf	6.00×10^{-05}	1.10×10^{-07}	4.11×10^{-09}	1.64×10^{-05}	1.10×10^{-05}	$2.50\times10^{+01}$
Cl	$3.32\times10^{+00}$	4.65×10^{-05}	4.65×10^{-05}	8.21×10^{-05}	7.39×10^{-03}	$4.70\times10^{+01}$
Cm	1.37×10^{-04}	1.10×10^{-07}	5.48×10^{-08}	1.64×10^{-05}	1.10×10^{-05}	$3.00\times10^{+01}$
Co	2.48×10^{-02}	1.18×10^{-06}	3.01×10^{-07}	2.66×10^{-03}	9.03×10^{-05}	$7.60\times10^{+01}$
Cr	1.93×10^{-04}	2.46×10^{-05}	1.18×10^{-06}	5.48×10^{-04}	2.46×10^{-03}	$4.00\times10^{+01}$
Cs	7.03×10^{-03}	6.02×10^{-05}	1.26×10^{-05}	7.39×10^{-03}	1.10×10^{-03}	$2.50\times10^{+03}$
Cu	5.42×10^{-02}	2.46×10^{-05}	5.48×10^{-06}	1.37×10^{-03}	1.37×10^{-03}	$2.30\times10^{+02}$
Dy	3.85×10^{-03}	5.48×10^{-08}	8.21×10^{-08}	5.48×10^{-06}	1.10×10^{-07}	$6.50\times10^{+02}$
Er	3.85×10^{-03}	5.48×10^{-08}	8.21×10^{-08}	5.48×10^{-06}	1.10×10^{-07}	$3.00\times10^{+01}$
Es	2.40×10^{-04}	6.84×10^{-08}	5.48×10^{-09}	1.00×10^{-20}	1.00×10^{-20}	$2.50\times10^{+01}$
Eu	3.85×10^{-03}	5.48×10^{-08}	8.21×10^{-08}	5.48×10^{-06}	1.10×10^{-07}	$1.30\times10^{+02}$
F	3.85×10^{-03}	4.11×10^{-04}	2.74×10^{-06}	3.83×10^{-05}	7.39×10^{-03}	$1.00\times10^{+01}$
Fm	4.80×10^{-04}	5.48×10^{-07}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
Fr	6.12×10^{-02}	6.84×10^{-06}	5.64×10^{-05}	1.00×10^{-20}	1.00×10^{-20}	$3.00\times10^{+01}$
Ga	2.21×10^{-04}	1.37×10^{-06}	1.37×10^{-07}	2.19×10^{-03}	2.74×10^{-03}	$4.00\times10^{+02}$
Gd	3.85×10^{-03}	5.48×10^{-08}	8.21×10^{-08}	5.48×10^{-06}	1.10×10^{-07}	$3.00\times10^{+01}$
Ge	3.20×10^{-02}	1.9210^{-03}	1.97×10^{-04}	1.00×10^{-20}	1.00×10^{-20}	$4.00\times10^{+03}$
H	$1.15\times10^{+00}$	1.00×10^{-20}	4.11×10^{-05}	1.00×10^{-20}	1.00×10^{-20}	$1.00\times10^{+00}$
Ha	4.80×10^{-04}	1.37×10^{-08}	1.37×10^{-08}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
He	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	$1.00\times10^{+00}$

Table 8. DOE Recommended Biotic Accumulation Transfer Coefficients (Continued)

Element	Soil-to-Plant	Fodder-to- Meat	Fodder-to- Milk	Fodder-to- Poultry	Fodder-to- Egg	Water-to-Fish
Hf	1.93×10^{-04}	2.74×10^{-06}	1.51×10^{-09}	1.64×10^{-07}	5.48×10^{-07}	$1.10\times10^{+03}$
Hg	8.52×10^{-02}	6.84×10^{-04}	1.29×10^{-06}	8.21×10^{-05}	1.37×10^{-03}	$6.10\times10^{+03}$
Ho	3.85×10^{-03}	8.21×10^{-07}	8.21×10^{-08}	5.48×10^{-06}	1.10×10^{-07}	$3.00\times10^{+01}$
I	1.07×10^{-02}	1.83×10^{-05}	1.48×10^{-05}	2.38×10^{-05}	6.57×10^{-03}	$3.00\times10^{+01}$
In	2.21×10^{-04}	2.19×10^{-05}	5.48×10^{-07}	2.19×10^{-03}	2.74×10^{-03}	$1.00\times10^{+04}$
Ir	4.49×10^{-03}	4.11×10^{-06}	5.48×10^{-09}	5.48×10^{-03}	2.74×10^{-04}	$1.00\times10^{+01}$
K	1.36×10^{-01}	5.48×10^{-05}	1.97×10^{-05}	1.10×10^{-03}	2.74×10^{-03}	$3.20\times10^{+03}$
Kr	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
La	8.78×10^{-04}	3.56×10^{-07}	5.48×10^{-08}	2.74×10^{-04}	2.46×10^{-5}	$3.70\times10^{+01}$
Li	1.80×10^{-03}	2.74×10^{-05}	5.64×10^{-05}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
Lr	4.80×10^{-04}	5.48×10^{-07}	1.37×10^{-08}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
Lu	1.20×10^{-03}	1.23×10^{-05}	5.64×10^{-08}	1.00×10^{-20}	1.00×10^{-20}	$2.50\times10^{+01}$
Md	4.80×10^{-04}	1.00×10^{-20}	1.37×10^{-08}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
Mg	1.24×10^{-01}	5.48×10^{-05}	1.07×10^{-05}	8.21×10^{-05}	5.48×10^{-03}	$3.70\times10^{+01}$
Mn	6.58×10^{-02}	1.64×10^{-06}	1.12×10^{-07}	5.20×10^{-06}	1.15×10^{-04}	$2.40\times10^{+02}$
Mo	8.44×10^{-02}	2.74×10^{-06}	3.01×10^{-06}	4.93×10^{-04}	1.75×10^{-03}	$1.90\times10^{+00}$
N	7.36×10^{-03}	2.05×10^{-04}	6.84×10^{-05}	2.68×10^{-04}	7.12×10^{-04}	$2.00\times10^{+05}$
Na	5.78×10^{-03}	4.11×10^{-05}	3.56×10^{-05}	1.92×10^{-02}	1.10×10^{-02}	$7.60\times10^{+01}$
Nb	2.18×10^{-03}	7.12×10^{-10}	1.12×10^{-09}	8.21×10^{-07}	2.74×10^{-06}	$3.00\times10^{+02}$
Nd	3.85×10^{-03}	5.48×10^{-08}	8.21×10^{-08}	5.48×10^{-06}	1.10×10^{-07}	$3.00\times10^{+01}$
Ne	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
Ni	2.04×10^{-02}	1.37×10^{-05}	2.60×10^{-06}	2.74×10^{-06}	2.74×10^{-04}	$2.10\times10^{+01}$
No	4.80×10^{-04}	5.48×10^{-07}	1.37×10^{-08}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
Np	4.05×10^{-03}	2.74×10^{-06}	1.37×10^{-08}	1.64×10^{-05}	1.10×10^{-05}	$2.10\times10^{+01}$
O	1.44×10^{-01}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	$1.00\times10^{+00}$
Os	6.19×10^{-03}	1.10×10^{-03}	1.37×10^{-05}	2.30×10^{-04}	1.94×10^{-04}	$1.00\times10^{+03}$
P	1.93×10^{-01}	1.51×10^{-04}	5.48×10^{-05}	5.20×10^{-04}	1.75×10^{-03}	$1.40\times10^{+05}$
Pa	6.00×10^{-05}	1.22×10^{-06}	1.37×10^{-08}	1.64×10^{-05}	1.10×10^{-05}	$1.00\times10^{+01}$
Pb	5.26×10^{-03}	1.92×10^{-06}	5.20×10^{-07}	2.19×10^{-03}	2.74×10^{-03}	$2.50\times10^{+01}$
Pd	1.21×10^{-02}	1.10×10^{-05}	2.74×10^{-05}	8.21×10^{-07}	1.10×10^{-05}	$1.00\times10^{+01}$
Pm	2.46×10^{-02}	5.48×10^{-08}	8.21×10^{-08}	5.48×10^{-06}	1.10×10^{-07}	$3.00\times10^{+01}$
Po	7.92×10^{-04}	1.37×10^{-05}	5.75×10^{-07}	6.57×10^{-03}	8.49×10^{-03}	$3.60\times10^{+01}$
Pr	4.80×10^{-03}	5.48×10^{-08}	8.21×10^{-08}	5.48×10^{-06}	1.10×10^{-07}	$3.00\times10^{+01}$
Pt	8.80×10^{-03}	1.10×10^{-05}	1.41×10^{-05}	1.00×10^{-20}	1.00×10^{-20}	$3.50\times10^{+01}$
Pu	2.19×10^{-05}	3.01×10^{-09}	2.74×10^{-08}	8.21×10^{-06}	3.29×10^{-06}	$3.00\times10^{+01}$
Ra	7.60×10^{-03}	4.65×10^{-06}	1.04×10^{-06}	8.21×10^{-05}	8.49×10^{-04}	$4.00\times10^{+00}$
Rb	2.05×10^{-01}	2.74×10^{-05}	3.29×10^{-05}	5.48×10^{-03}	$8..21\times10^{-03}$	$4.90\times10^{+03}$
Re	1.13×10^{-01}	2.19×10^{-05}	4.11×10^{-06}	1.10×10^{-04}	1.15×10^{-03}	$1.20\times10^{+02}$

Table 8. DOE Recommended Biotic Accumulation Transfer Coefficient (Continued)

Element	Soil-to-Plant	Fodder-to-				Water-to-Fish
		Meat	Milk	Poultry	Egg	
Rf	7.20×10^{-04}	1.00×10^{-20}	5.48×10^{-08}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
Rh	1.86×10^{-01}	5.48×10^{-06}	2.74×10^{-05}	5.48×10^{-03}	2.74×10^{-04}	$1.00\times10^{+01}$
Rn	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	7.55×10^{-10}
Ru	6.39×10^{-03}	9.03×10^{-06}	2.57×10^{-08}	1.92×10^{-05}	1.10×10^{-05}	$5.50\times10^{+01}$
S	2.89×10^{-01}	5.48×10^{-04}	2.16×10^{-05}	6.30×10^{-03}	1.92×10^{-02}	$8.00\times10^{+02}$
Sb	2.95×10^{-04}	3.29×10^{-06}	1.04×10^{-07}	1.64×10^{-05}	1.92×10^{-04}	$3.70\times10^{+01}$
Sc	3.93×10^{-04}	4.11×10^{-05}	1.37×10^{-08}	1.10×10^{-05}	1.15×10^{-05}	$1.90\times10^{+02}$
Se	1.76×10^{-02}	4.11×10^{-05}	1.10×10^{-05}	2.66×10^{-02}	4.38×10^{-02}	$6.00\times10^{+03}$
Si	2.47×10^{-02}	1.10×10^{-07}	5.48×10^{-08}	2.19×10^{-03}	2.74×10^{-03}	$2.00\times10^{+01}$
Sm	3.85×10^{-03}	8.65×10^{-07}	8.21×10^{-08}	5.48×10^{-06}	1.10×10^{-07}	$3.00\times10^{+01}$
Sn	2.12×10^{-03}	2.19×10^{-04}	2.74×10^{-06}	2.19×10^{-03}	2.74×10^{-03}	$3.00\times10^{+03}$
Sr	1.37×10^{-01}	3.56×10^{-06}	3.56×10^{-06}	5.48×10^{-05}	9.58×10^{-04}	$2.90\times10^{+00}$
Ta	4.82×10^{-03}	3.67×10^{-08}	1.12×10^{-09}	8.21×10^{-07}	2.74×10^{-06}	$3.00\times10^{+02}$
Tb	3.85×10^{-03}	5.48×10^{-08}	8.21×10^{-08}	5.48×10^{-06}	1.10×10^{-07}	$4.10\times10^{+02}$
Tc	$1.14\times10^{+01}$	1.73×10^{-05}	5.12×10^{-06}	8.21×10^{-05}	8.21×10^{-03}	$2.00\times10^{+01}$
Te	5.78×10^{-02}	1.92×10^{-05}	9.31×10^{-07}	1.64×10^{-03}	1.40×10^{-02}	$1.50\times10^{+02}$
Th	1.65×10^{-04}	6.30×10^{-07}	1.37×10^{-08}	1.64×10^{-05}	1.10×10^{-05}	$6.00\times10^{+00}$
Ti	8.20×10^{-04}	8.21×10^{-05}	2.82×10^{-05}	1.00×10^{-20}	1.00×10^{-20}	$1.90\times10^{+02}$
Tl	2.21×10^{-04}	1.10×10^{-04}	5.48×10^{-06}	2.19×10^{-03}	2.74×10^{-03}	$9.00\times10^{+02}$
Tm	1.20×10^{-03}	1.23×10^{-05}	5.64×10^{-08}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
U	2.58×10^{-03}	1.07×10^{-06}	4.93×10^{-06}	2.05×10^{-03}	3.01×10^{-03}	9.60×10^{-01}
V	8.20×10^{-04}	6.84×10^{-06}	5.64×10^{-08}	1.00×10^{-20}	1.00×10^{-20}	$9.70\times10^{+01}$
W	5.78×10^{-01}	1.10×10^{-04}	5.20×10^{-07}	5.48×10^{-04}	2.46×10^{-03}	$1.00\times10^{+01}$
Xe	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
Y	3.85×10^{-04}	2.74×10^{-06}	5.48×10^{-08}	2.74×10^{-05}	5.48×10^{-06}	$4.00\times10^{+01}$
Yb	1.20×10^{-03}	1.10×10^{-05}	5.64×10^{-08}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
Zn	1.79×10^{-01}	4.38×10^{-04}	7.39×10^{-06}	1.29×10^{-03}	3.83×10^{-03}	$3.40\times10^{+03}$
Zr	7.70×10^{-04}	3.29×10^{-09}	9.86×10^{-09}	1.64×10^{-07}	5.48×10^{-07}	$2.20\times10^{+01}$
Probabilistic Multiplier						
Distribution	Log-Normal	Log-Normal	Log-Normal	N/A	N/A	Log-Normal
GM	1.0	1.0	1.0	N/A	N/A	1.0
GSD	3.7	5.8	3.0	N/A	N/A	2.7
Min.	0.073	0.15	0.3	N/A	N/A	0.29
Max.	51.4	46	12	N/A	N/A	25

Note: Adapted from Tables 7.3-1 through 7.3-6 of SRR-CWDA-2013-00058, Rev. 1.
GM: Geometric Mean; GSD: Geometric Standard Deviation
Min.: Minimum; Max.: Maximum
N/A: Not Applicable

Rev. 1). If the sources of transfer coefficients in the hierarchy all lack a value, DOE uses a value of 1.00×10^{-20} because DOE expects it to have a negligible effect on the doses, but needs to use a non-zero value to avoid numerical errors in the dose calculations. Once a transfer coefficient value is selected from the top-most source in the hierarchy, DOE compares the value to the transfer coefficient used for the HTF PA, Rev. 1 (SRR-CWDA-2010-00128, Rev. 1) and recommends either the selected value from the hierarchy of sources if the HTF PA, Rev. 1 transfer coefficient is not a geometric mean of transfer factors from multiple sources or the higher of the two values when the HTF PA, Rev. 1 transfer coefficient is a geometric mean. For soil-to-plant transfer factors, when wet-weight values are provided by the hierarchy of sources, DOE applies a dry-to-wet ratio of 0.195 so that all transfer coefficients have consistent units.

To develop probabilistic distributions for multipliers, DOE selects values that are consistent with those developed for DOE's Yucca Mountain Project for fodder-to-meat and fodder-to-milk transfer coefficients (MDL-MGR-MD-000001, Rev. 2). DOE does not recommend a probabilistic distribution for a multiplier for any of the poultry or egg pathways because DOE does not expect them to be a significant contributor to dose relative to other ingestion pathways.

Exposure and Inhalation Parameters

Table 9 summarizes the values recommended by DOE for exposure and inhalation parameters for the deterministic modeling and the recommended distribution values for multipliers for the probabilistic modeling for selected parameters. DOE determines the recommended values for exposure and inhalation parameters from various sources as described in the following paragraphs. DOE does not provide recommended values for probabilistic multipliers for parameters (e.g., time spent boating) that DOE does not expect to be significant contributors to dose relative to other exposure pathways.

Time Spent Gardening

DOE determines the recommended time spent gardening in a year for the deterministic modeling by converting to a fractional value the average total daily time spent by U.S. civilian population ages 15 years and older performing lawn and garden care from Table 16-100 of EPA/600/R-09/052F and normalizing (i.e., dividing) by the fraction of total households that have gardens from Table 13-71 of EPA/600/R-09/052F. To determine the recommended values for the multiplier distribution for the probabilistic modeling, DOE assumes the minimum is one-half and the maximum is double the recommended deterministic value.

Time Spent Showering/Bathing

DOE determines the recommended time spent showering/bathing in a year for deterministic modeling by converting to a fractional value the EPA's recommended mean value for time spent in the bathing/showering activity pattern per day for the 18 to <65 years age group from Table 16-1 of EPA/600/R-09/052F. DOE developed the recommended probabilistic distribution values

Table 9. DOE Recommended Exposure and Inhalation Parameter Values

Parameter	Unit	Deterministic Value	Probabilistic Multiplier				
			Distribution	Mean/ Mode	SD	Min.	Max.
Fraction of Time Spent in a Contaminated Garden*	-	2.7×10^{-2}	Triangular	1.0	N/A	0.5	2.0
Fraction of Time Spent Showering or Bathing*	-	1.2×10^{-2}	Log-Normal	0.85	0.65	0.25	1.52
Geometry Factor for Showering or Bathing†	-	1	N/A	N/A	N/A	N/A	N/A
Fraction of Time Spent Swimming*	-	1.7×10^{-3}	Triangular	1.0	N/A	0	3.3
Geometry Factor for Swimming†	-	1	N/A	N/A	N/A	N/A	N/A
Fraction of Time Spent Boating*	-	2.5×10^{-3}	N/A	N/A	N/A	N/A	N/A
Geometry Factor for Boating†	-	0.5	N/A	N/A	N/A	N/A	N/A
Fraction of Time Spent Drilling into Contaminated Source*	-	2.3×10^{-3}	Triangular	1.0	N/A	0.1	2.0
Airborne Release Fraction	-	1.0×10^{-4}	Uniform	N/A	N/A	0.04	2.0
Moisture Content of Ambient Air	kg/m^3	0.01‡	N/A	N/A	N/A	N/A	N/A
Moisture Content of Shower Air	kg/m^3	0.041§	N/A	N/A	N/A	N/A	N/A
Mass Loading of Soil in the Air	kg/m^3	1.0×10^{-7}	Triangular	1.0	N/A	0.1	3.0

Note: Adapted from Table 7.4-1 of SRR-CWDA-2013-00058, Rev. 1.
* The fraction of time spent performing the activity is on an annual basis
†The geometry factor is the fraction of the human body that DOE assumes to be exposed to contaminants during a specific activity.
‡ From DOE-HDBK-3010-94, Vol. I, Table 3-6
§ From HNF-SD-WM-TI-707, Rev. 3, Table A12

SD: Standard Deviation
Min.: Minimum; Max.: Maximum
N/A: Not Applicable

for the time spent showering/bathing in a year based on the duration of shower from on Table 16-32 of EPA/600/R-09/052F. DOE normalized the percentiles for all population groups by the mean value for time spent in the bathing/showering activity pattern per day for the 18 to <65 years age group from Table 16-1. Through trial and error, DOE found a log-normal distribution with the recommended distribution statistic values that provided a close match to the normalized EPA percentile values and truncated the distribution at the 10^{th} and 90^{th} percentiles.

Time Spent Swimming

DOE determines the recommended fraction of time spent swimming in a year for the deterministic modeling by converting to a fractional value the calculated mean of 10,000 samples of a discrete distribution populated by the percentiles reported in Table 16-42 of EPA/600/R-09/052F for minutes swimming per month for the 18 to 64 years population group.

To determine the recommended values for the multiplier distribution for the probabilistic modeling, DOE assumes the minimum is zero and sets the maximum multiplier so that the scaled time spent swimming is equivalent to a maximum of 181 minutes per month[9].

Time Spent Boating

DOE determines the recommended fraction of time spent boating for the deterministic modeling by converting to a fractional value the time per year spent boating from Table 10 of SRNL-STI-2010-00447, Rev. 0, which is based on 2005 data from the Georgia Department of Natural Resources and the South Carolina Department of Parks and Recreation and on the estimated hours per occasion from WSRC-RP-91-17.

Time Spent Drilling

DOE assumes that the IHI requires 20 hours to install a well. DOE converts this to an annual fractional value for the recommended value for deterministic modeling.

Airborne Release Fraction

DOE recommends an airborne release faction value for contaminants released to the air during irrigation, showering/bathing, and swimming for the deterministic modeling that is half the bounding value and two and a half times greater than the median value of airborne release fractions determined for aqueous solutions subjected to free-fall spills reported in Section 3.2.3.1 of DOE-HDBK-3010-94, Vol. I.

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[9] Table EPA/600/R-09/052F reports 181 minutes for all survey responses that exceeded 180 minutes per month.

Mass Loading of Soil in the Air

DOE recommends a value for the deterministic modeling that is selected from WSRC-RP-94-218. In WSRC-RP-94-218, DOE assumes an atmospheric mass loading of contaminated soil while working in the vegetable garden and justifies the assumption by identifying the assumed value (i) as a somewhat conservative approximation of the average background dust loading for nonurban locations in the U.S. according to Anspaugh et al. (1975) and (ii) is in good agreement with an average dust loading measured above two agricultural fields at SRS (Shinn et al., 1982).

<u>Soil Parameters</u>

Table 10 summarizes the values recommended by DOE for soil parameters for the deterministic modeling and the recommended distribution values for multipliers for the probabilistic modeling for selected parameters. The notes to Table 10 summarize DOE's justification for each value.

<u>Crop and Gardening Parameters</u>

Table 11 summarizes the values recommended by DOE for crop and gardening parameters for the deterministic modeling and the recommended distribution values for multipliers for the probabilistic modeling for selected parameters.

Table 10. DOE Recommended Soil Parameter Values

Parameter	Unit	Deterministic Value	Probabilistic Multiplier				
			Distribution	Mean/ Mode	SD	Min.	Max.
Buildup Time of Radionuclides in Soil*	yr	25	N/A	N/A	N/A	N/A	N/A
Surface (or Areal) Density of Soil†	kg/m^2	240	Normal‡	1.0	0.07	0.83	1.15
Dry Bulk Density of Soil§	kg/m^3	1650					
Precipitation Rate§§	m/yr	1.25	N/A	N/A	N/A	N/A	N/A
Evapotranspiration Rate#	m/yr	0.79	N/A	N/A	N/A	N/A	N/A
Irrigation Rate##	m/yr	1.32	Triangular	1.0	N/A	0.5	1.5
Weathering Decay Constant&	1/yr	18.1	Triangular	1.0	N/A	0.6	1.0
Soil Moisture Content&&	-	0.2086	N/A	N/A	N/A	N/A	N/A

Note: Adapted from Table 7.5-1 of SRR-CWDA-2013-00058, Rev. 1.
* DOE selects the largest buildup time for deterministic modeling of those presented in SRNL-STI-2010-00447, Rev 0, Table 1
† DOE estimated the recommended surface density of soil value for deterministic modeling by multiplying the assumed garden depth (i.e., 0.15 m) and the dry bulk density value reported in WSRC-STI-2007-00004, Rev. 4 (i.e., 1600 kg/m^3). See Section 3.6 of WSRC-STI-2007-00004, Rev. 4.
‡ DOE selects the normal distribution for probabilistic modeling based on Simpkins and Hamby (1993). DOE recommends surface soil density and dry bulk density of soil be modeled with a perfect (i.e., unity) correlation.
§ DOE assumes an Upper Vadose Zone soil and selects values for deterministic and probabilistic modeling to be consistent with average, minimum, and maximum reported in WSRC-STI-2006-00198, Rev. 0, Table 5-9
§§ DOE selects the average annual precipitation rate from Table 14 of WSRC-STI-2007-00184, Rev. 2, which contains precipitation data from 1961-2006 that was recorded at the 200-F weather station, for the recommended value for deterministic modeling.
# DOE recommends the median annual evapotranspiration rate determined from nominal rates estimated by eight studies, which are summarized in Table 9 of WSRC-STI-2007-00184, Rev. 2, for deterministic modeling.
DOE assumes an irrigation rate of 1 in. (0.254 cm) per week for the recommended value for deterministic modeling. DOE assumes an irrigation rate of 0.5 cm per day for the recommended maximum value for probabilistic modeling. See Table 3-2 of WSRC-STI-2007-00004, Rev. 4.
& DOE bases recommended value for deterministic modeling on 14-day half-life for removal of activity from plants. See Table 3-2 of WSRC-STI-2007-00004, Rev. 4.
&& DOE references SRR-CWDA-2010-00128, Rev. 1, Table 4.6-8, which references WSRC-STI-2007-00184, Rev. 2.

SD: Standard Deviation
Min.: Minimum
Max.: Maximum
N/A: Not Applicable

Table 11. DOE Recommended Crop and Gardening Parameter Values

Parameter	Unit	Deterministic Value	Probabilistic Multiplier				
			Distribution	Mean/ Mode	SD	Min.	Max.
Fraction Of Material Deposited On Leaves That Is Retained*	-	0.25	Triangular	1.0	N/A	0.8	1.0
Fraction Of Material Remaining On Leaves After Washing†	-	1	N/A	N/A	N/A	N/A	N/A
Time In Which Crops and Gardens Are Irrigated‡	yr	1.92×10^{-1}	Normal	1.0	0.1	0.85	1.28
Crop And Garden Yield§	kg/m^2	2.2	Log-Normal	1.0	0.23	0.1	1.8
Depth Of Crop Garden Tilling§§	m	0.15	Triangular	1.0	N/A	1.0	4.1
Fraction Of Produce That Is Leafy#	-	0.2	N/A	N/A	N/A	N/A	N/A
Area of Garden##	m^2	100	Triangular	1.0	N/A	1.0	10.0

Note: Adapted from Table 7.5-2 of SRR-CWDA-2013-00058, Rev. 1.
* DOE selects the fraction of material retained value from RG 1.109, Rev. 1 (ML003740384), for deterministic modeling. See Table 3-2 of WSRC-STI-2007-00004, Rev. 4. DOE also recommends, consistent with the footnote to Table 3-2, which references RG 1.109, Rev. 1 (ML003740384), that the fraction of material retained be 1 (i.e., 0.25 × 4) for iodine. DOE selects the recommended values of the probabilistic distribution based on values from Table 3-2. A footnote to the maximum value in Table 3-2 recommends setting this value to ensure a fraction of material retained equal to one (i.e., a maximum multiplier of 4) for iodine, or for all if the model is not able to handle iodine separately.
† DOE assumes all the material will remain on the leaves after washing.
‡ DOE assumes in Table 3-2 of WSRC-STI-2007-00004, Rev. 4 that the fraction of time the garden will be irrigated will be 70 days per year for the deterministic modeling. In Table 3-2, DOE also recommended a minimum of 70 days and a maximum of 90 days.
§ DOE recommends the crop yield for deterministic modeling based on a weighted average vegetable productivity for South Carolina and Georgia (USDA, 2009) as discussed in Section 3.1.1.1 of SRNL-STI-2010-00447, Rev. 0. DOE does not identify the basis for recommended values for the probabilistic modeling, but they appear to be consistent with values reported in Table 3-1 of WSRC-STI-2007-00004, Rev. 4, which were based on WSRC-RP-91-17.
§§ DOE recommends the garden depth values based on the value reported in Table 3-2 of WSRC-STI-2007-00004, Rev. 4, which references WSRC-RP-93- 1174.
# DOE recommends the leafy fraction of produce based on USDA (2009) data for the SRS region. See Section 3.1.2 of SRNL-STI-2010-00447, Rev. 0.
DOE estimates the recommended area of the garden by considering a family of four, vegetable consumption rates, the fraction of food produced locally, and crop yields as reported in Section 3.4 of WSRC-STI-2007-00004, Rev. 4. However, using the deterministic values of the produce consumption rate, the fraction of food produced locally, and crop yield reported in SRR-CWDA-2013-00058, Rev. 1, the area of the garden would be approximately equal to 16 m^2 for a family of four.

SD: Standard Deviation
Min.: Minimum, Max.: Maximum, N/A: Not Applicable

IHI Drilling Parameters

Table 12 summarizes the values recommended by DOE for drilling parameters for the IHI deterministic modeling and the recommended distribution values for multipliers for the probabilistic modeling for selected parameters.

Table 12. DOE Recommended IHI Drilling Parameter Values

Parameter	Unit	Deterministic Value	Probabilistic Multiplier				
			Distribution	Mean/ Mode	SD	Min.	Max.
Well Diameter*	m	0.203	N/A	N/A	N/A	N/A	N/A
Transfer Line Area Per Length†	m^2/m	0.245	N/A	N/A	N/A	N/A	N/A
Water Density‡	kg/L	1	N/A	N/A	N/A	N/A	N/A
Well Depth§	m	30.5	Log-Normal	1.85	0.75	0.3	9.9

Note: Adapted from Table 7.5-3 of SRR-CWDA-2013-00058, Rev. 1.
* DOE recommends a well diameter for deterministic modeling based on SRR-CWDA-2010-00054, Rev. 0, which surveyed SRS-area well installations. The results of the survey indicated a 4-in (10-cm) diameter casing was the predominate installation. DOE assumes that the wellbore is at least 3 in (8 cm) larger due to South Carolina annular space requirements.
† From SRR-CWDA-2010-00128, Rev. 1, Table 4.6-8. Applicable to TFs.
‡ Assumed value.
§ For deterministic modeling, DOE recommends a shallow value compared to well completion depth data in the vicinity of SRS (see SRR-CWDA-2010-00054, Rev. 0) to minimize dilution with drill cuttings for the IHI scenario. For the probabilistic modeling, DOE fit a log-normal distribution to well completion depth data, discussed in SRR-CWDA-2010-00054, Rev. 0, to determine the multiplier distribution parameters. The log-normal distribution reflects DOE's expected aquifer distributions of 13%, 44% and 43% for the Upper Three Runs Aquifer, Lower Three Runs Aquifer, and the Gordon Aquifer, respectively.
SD: Standard Deviation
Min.: Minimum
Max.: Maximum
N/A: Not Applicable

Distribution Coefficients (K_ds)

Table 13 summarizes the values recommended by DOE for soil buildup model K_ds for the deterministic modeling and the recommended distribution values for the probabilistic modeling. DOE selects sandy soil K_ds for the recommended values.

Table 13. DOE Recommended Soil Buildup Model K_ds

Deterministic Modeling

Element	K_d (L/kg)	Element	K_d (L/kg)	Element	K_d (L/kg)
Ac[*]	1,100	**Cu**[*]	50	**Pt**[*]	7
Ag[†]	10	**Eu**[*]	1,100	**Pu**[§§]	650
Al[*]	1,300	**Fe**[*]	200	**Ra**[‡]	25
Am[*]	1,100	**Fr**[*]	10	**Rb**[*]	10
As[*]	100	**Gd**[*]	1,100	**Re**[*]	0.6
At[*]	0.3	**Hg**[*]	800	**Sb**[*]	2,500
Ba[‡]	15	**I**[##]	1	**Se**[*]	1,000
Bi[*]	1,100	**K**[*]	5	**Sm**[*]	1,100
Bk[*]	1,100	**Lu**[*]	1,100	**Sn**[*]	2,000
C[*]	10	**Mn**[*]	15	**Sr**[‡]	5
Ca[*]	5	**Mo**[*]	1,000	**Tc**[*]	0.6
Cd[*]	15	**Na**[*]	5	**Te**[*]	1,000
Ce[*]	1,100	**Nb**[§]	160	**Th**[*]	900
Cf[*]	1,100	**Ni**[*]	7	**Tl**[#]	25
Cl[†]	1	**Np**[*]	3	**U**[#]	300
Cm[*]	1,100	**Pa**[*]	3	**Y**[*]	1,100
Co[*]	40	**Pb**[*]	2,000	**Zn**[*]	15
Cr[†]	1,000	**Pd**[*]	7	**Zr**[*]	900
Cs[*]	10	**Po**[*]	2,000		

Probabilistic Modeling

IF Condition	Log-Normal Distribution			
	GM	**GSD**	**Min.**	**Max.**
Kd < 2.7 L/kg	K_d	1.001	K_d × 0.25	K_d × 1.75
Kd ≥ 2.7 L/kg	K_d	K_d × 0.375	K_d × 0.25	K_d × 1.75

Note: Adapted from Table 7.7-1 of SRR-CWDA-2013-00058, Rev. 1.
DOE assumes that any elements not listed in this table will have a minimal impact on soil buildup calculation with respect to dose and may be assigned a value of 1.0×10^{-20} L/kg.

* From SRNL-STI-2009-00473, Table 16
† From SRNL-STI-2010-00493, Rev. 0, Table 9
‡ From SRNL-STI-2011-00011, Rev. 0, Table 2-2
§ From Prikryl and Pickett, 2007 (ML073510127), Section 2.4.5
§§ From SRNL-STI-2011-00672, Section 5
# From SRNL-STI-2010-00493, Rev. 0, Table 8
From SRNL-STI-2012-00518, Rev. 0, Table 9

GM: Geometric Mean
GSD: Geometric Standard Deviation
Min.: Minimum
Max.: Maximum

<u>NRC Staff Evaluation</u>

Human Receptor Definitions, Exposure Pathways, and Dose Calculations

Demonstration that the 10 CFR Part 61 performance objectives are met is typically made through an evaluation exposure pathways for a receptor who represents an average member of the critical group[10]. DOE considers an all-pathways exposure scenario that is widely used in PAs and is well-suited for the purpose. DOE's calculations are well documented and appropriate for the purpose. DOE's receptor, the reference person, which is age- and gender-weighted, differs from both the average member of the critical group and the more recent representative person[11] concepts. Both the average member of the critical group and representative person concepts entail an assessment of the more highly exposed individuals in the population, who may have different characteristics than the population as a whole. For these reasons, and as discussed further in subsequent paragraphs, DOE should provide additional justification that the reference person is equivalent to the average member of the critical group used to demonstrate that the 10 CFR Part 61 performance objectives are met.

For prospective assessments of the disposal of long-lived radionuclides, ICRP has stated it is reasonable to calculate the annual dose averaged over the lifetime of the individuals, which means that it is not necessary to calculate doses to different age groups; this average can be adequately represented by the annual dose to an adult (ICRP, 1998). Similarly, NRC recommends that the average member of the critical group for demonstration of compliance with 10 CFR Part 61 performance objectives typically can be assessed for an adult since they are generally exposed to greater number of pathways.

While NRC guidance continues to recommend a single adult dose conversion factor (rather than age- and gender-weighting) for the average member of the critical group, ICRP's recommendations in Publication 103 (ICRP, 2007) support gender-weighting. ICRP in its recommendations equally weights the genders. DOE has elected to weight genders based on their proportion in the U.S. population. DOE has not provided a basis for the applicability of U.S. population data to the average member of the critical group for SRS. However, NRC staff does not expect that any regional variation in gender would be significantly different.

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[10] The critical group is the group of individuals reasonably expected to receive the greatest exposure to radioactivity for any applicable set of circumstances.

[11] ICRP defines the representative person, a hypothetical construct used to determine compliance with the dose constraint, in Publication 101 (ICRP, 2006). ICRP Publication 101 indicates that the representative person receives a dose that is representative of the more highly exposed individuals in the population and is equivalent to, and replaces, the average member of the critical group recommended previously by the ICRP.

Lastly, DOE's use of median habits of the entire U.S. population for the habits of its reference person in the SRS PAs is inconsistent with the average member of the critical group concept typically used to demonstrate compliance with the 10 CFR Part 61 performance objectives because the habits of the critical group for SRS PAs may be different than those of the entire U.S. population. DOE has not provided a basis to support the use of U.S. population survey data in lieu of characteristics of the more highly exposed individuals in the population. Further, DOE has not provided a justification for use of median habits of the U.S. population. ICRP in its recommendations in Publication 103 (ICRP, 2007) indicates that if data on the representative person is not available, national population data can be relied upon, but identifies the use of the 95^{th} percentile of the survey data as a cautious approach. DOE should provide a basis to support the use of median U.S. population survey data in lieu of characteristics of the average member of the critical group or rely on characteristics associated with the 95^{th} percentile of survey distributions to ensure a cautious approach. Additional discussion of the selection of receptor habits and characteristics is provided in the following sections regarding parameter values and distributions.

Parameter Values and Distributions

In general, DOE provides a transparent and traceable basis for recommended parameter classes including dose conversion factors, human and animal consumption rates, locally-produced foods, transfer coefficients, exposure and inhalation parameters, soil parameters, crop and gardening parameters, IHI drilling parameters, and sorption coefficients used in SRR-CWDA-2013-00058, Rev. 1. NRC staff's review of individual parameters within each parameter class are provided below.

<u>Dose Conversion Factors</u>

Section 4.6.1.3 of NUREG-1854 recommends that DOE use dosimetry consistent with 10 CFR Part 20 to ensure consistency between the various 10 CFR Part 61 performance objectives, but recognizes that DOE can use more recent dose coefficients, provided the dosimetry is used consistently for all parts of the analysis, to the extent practicable. Rather than relying on dose coefficients recommended in FGRs 11 and 12 (EPA-520/1-88-020; EPA-402-R-93-081) or ICRP Publication 72 (ICRP, 1995), DOE elected to develop dose coefficients. The primary difference between DOE's developed dose coefficients and those published in FGRs 11 and 12 (EPA-520/1-88-020; EPA-402-R-93-081) or ICRP Publication 72 (ICRP, 1995) is that DOE age- and gender-weights the dose coefficients to develop general population dose coefficients, whereas, the dose coefficients in the FGRs 11 and 12 published only adult dose coefficients and considered them protective of the general population, while ICRP Publication 72 (ICRP, 1995) and FGR 13 (EPA-402-R-99-001) developed dose and risk coefficients, respectively, for various distinct age groups. Further, DOE uses revised gender-specific physiological parameters from ICRP Publication 89 (ICRP, 2002) and more recent information on energies and intensities of

radiations emitted by radionuclides from ICRP Publication 107 (ICRP, 2008) to develop dose coefficients for use in DOE PAs.

DOE's approach for determining dose coefficients for an age- and gender-weighted reference person is generally acceptable for demonstrating that the 10 CFR Part 61 performance objectives will be met except where noted because the coefficients are developed in a manner that is generally consistent with the development of coefficients reported in FGRs[12] on radiation protection for internal and external exposures, provided that DOE's reference person characteristics are consistent with the average member of the critical group concept (and more recent, though similar, representative person concept discussed in ICRP Publication 103 [ICRP, 2007]. However, NRC staff notes that DOE has recommended values for inhalation dose coefficients associated with lung absorption type F for all radionuclides but has not justified in SRR-CWDA-2013-00058, Rev. 1 the use of inhalation dose coefficients associated with this lung absorption type. DOE should provide a technical basis for the use of inhalation dose coefficients associated with an appropriate lung absorption type or, in the absence of a technical basis, should recommend the dose coefficients associated with a lung absorption type that are most conservative.[13]

NRC staff will continue to monitor DOE's dose conversion factors under Monitoring Factor 6.2, "Model and Parameter Support," in the SRS TFs Monitoring Plan (ML15238B403). NRC staff is also expanding Monitoring Factor 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors," in the SDF Monitoring Plan (ML13100A076) to include the dose conversion factors and will also monitor the dose conversion factors under this Monitoring Factor.

Human Uptake Parameters

Human uptake parameters identified in Tables 4 and 6 are either behavioral (e.g., consumption rates) or metabolic (e.g., breathing rate). As discussed in NUREG-1854 and NUREG-1573, behavioral and metabolic parameters should be representative of the average member of the critical group in the modeled exposure scenario and should be based upon regional or local habits and characteristics if these data are available. Generic parameter values found in the literature should be documented as to their applicability to the expected site conditions and an attempt to represent a best estimate of the actual values at the site. A minimum number of sources of generic data should be used to maintain internal consistency.

NRC staff has identified issues with consumption rates under Monitoring Factors 6.2, "Model and Parameter Support," and 10.08, "Consumption Factors and Uncertainty Distributions for

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[12] Federal Guidance Reports 11 (EPA-520/1-88-020), 12 (EPA-402-R-93-081), and 13 (EPA-402-R-99-001).
[13] DOE-STD-1196-2011 also recommends that if specific information on the chemical form is lacking to identify a lung adsorption class, the most restrictive dose coefficient should be assumed.

Transfer Factors," in the respective SRS TFs (ML15238B403) and SDF (ML13100A076) Monitoring Plans. In SRR-CWDA-2013-00058, Rev. 1, DOE has not provided a justification for the applicability of U.S. population survey data from EPA/600/R-09/052F to the average member of the critical group for SRS PAs. Further, in recommending human uptake values, DOE frequently departs from its reference person definition by relying upon mean rather than median values. In some cases, even though DOE may not have adequately justified the use of national survey data in lieu of regional or local data or may have departed from its own definition of reference person median characteristics and habits, the parameter values may still be acceptable for use in SRS PAs.

In addition, DOE's development of probabilistic distribution parameter values based on U.S. population survey data are generally subject to the same concerns raised about the application of U.S. population behaviors to the average member of the critical group and are not discussed further for each parameter below. Also, if DOE were to justify the appropriateness of U.S. population survey data to the average member of the critical group for SRS PAs, DOE should provide a basis for the selection of parameter distributions and goodness-of-fit statistics for selected probabilistic distributions that were developed through trial and error fits to U.S. population survey data from EPA/600/R-09/052F. DOE should also improve the clarity of how the distributions are developed. NRC staff were not able to independently confirm the development of probabilistic distributions from DOE's descriptions.

Discussion of NRC staff's review of individual parameters and their supporting justifications follows:

- *Contaminated Water Consumption* – DOE's recommended contaminated water consumption rate is smaller than the default water consumption rate for the DandD code listed in Table 6.87 of NUREG/CR-5512, Vol. 3. Further, DOE has not provided justification for the applicability of either bottled water consumption as a surrogate for non-contaminated water consumption at SRS or the use of median values from U.S. population survey data from EPA/600/R-09/052F for total water consumed by the "All Ages" group to the average member of the critical group at SRS. DOE should justify a contaminated water consumption rate based on regional or local characteristics and habits that would be expected to be consistent with the average member of the critical group for SRS PAs.

- *Soil and Dust Consumption* – Although DOE has not provided justification for the applicability of U.S. population survey data from EPA/600/R-09/052F for total soil and dust consumed to the average member of the critical group at SRS, NRC staff finds DOE's recommended soil and dust consumption rate acceptable for use in the deterministic modeling for SRS PAs. The recommended rate is derived from the central tendency for children from Table 5-1 of EPA/600/R-09/052F and is twice the default value for the residential scenario for the DandD code[14] from Table 6.87 of NUREG/CR-5512, Vol. 3. For the probabilistic modeling, DOE set the multiplier so that the distribution would range from half to twice the recommended value. The upper end of this range is consistent with the general population upper percentile reported in Table 5-1 of EPA/600/R-09/052F and is more than twice the maximum value for default sampling statistics listed in Table 6.87 of NUREG/CR-5512, Vol. 3 and adequate for use in the SRS PAs.

- *Produce Consumption* – Although DOE has not provided justification for the applicability of U.S. population survey data from EPA/600/R-09/052F for total produce consumed by the “All Ages” group to the average member of the critical group at SRS, NRC staff finds that DOE’s recommended produce consumption rate acceptable for use in the deterministic modeling for SRS PAs. The recommended rate is derived from the mean for the “All Ages” group from Table 9-8 of EPA/600/R-09/052F. DOE’s recommended rate is larger than the largest per capita rate for the adult age groups identified in Table 9-1 of EPA/600/R-09/052F (assuming 80 kg mass for an adult) and consistent with the combined consumption rates for leafy and other vegetables, fruits, and grain listed in Table 6.87 of NUREG/CR-5512, Vol. 3.

- *Meat Consumption* – Although DOE has not provided justification for the applicability of U.S. population survey data from EPA/600/R-09/052F for total meat consumed by the “All Ages” group to the average member of the critical group at SRS, NRC staff finds that DOE’s recommended meat consumption rate value acceptable for use in the deterministic modeling for SRS PAs. The recommended value is the mean for the “All Ages” group from Table 11-7 of EPA/600/R-09/052F. DOE’s recommended value is larger than the largest per capita rate for the adult age groups identified in Table 11-1 of EPA/600/R-09/052F (assuming 80 kg mass for an adult) and larger than the default beef consumption rate for the DandD code listed in Table 6.87 of NUREG/CR-5512, Vol. 3.

- *Milk Consumption* – DOE’s recommended milk consumption rate is smaller than the default milk consumption rate for the DandD code listed in Table 6.87 of NUREG/CR-5512, Vol. 3. Further, DOE has not provided justification for the applicability of U.S. population survey data from EPA/600/R-09/052F for total fluid milk consumed by the average member of the critical group at SRS. DOE should justify a milk consumption rate based on regional or local characteristics and habits that would be expected to be consistent with the average member of the critical group for SRS PAs.

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[14] NUREG/CR-5512, Vol. 3 provides an approved set of default parameter values and distributions for the DandD code, which NRC has endorsed for conservative screening analyses involving residual radioactivity in the biosphere.

- *Poultry and Egg Consumption* – DOE's recommended poultry and egg consumption rates are smaller than the respective default poultry and egg consumption rates for the DandD code listed in Table 6.87 of NUREG/CR-5512, Vol. 3. Further, DOE has not provided justification for the applicability of U.S. population survey data from EPA/600/R-09/052F for poultry and egg consumed to the average member of the critical group at SRS. DOE should justify poultry and egg consumption rates based on regional or local characteristics and habits that would be expected to be consistent with the average member of the critical group for SRS PAs.

- *Fish Consumption* – DOE's recommended fish consumption rate is smaller than the default fish consumption rate for the DandD code listed in Table 6.87 of NUREG/CR-5512, Vol. 3. Further, DOE has not provided justification for the applicability of U.S. population survey data from EPA/600/R-09/052F for fish consumed to the average member of the critical group at SRS. DOE should justify the fish consumption rate based on regional or local characteristics and habits that would be expected to be consistent with the average member of the critical group for SRS PAs.

- *Breathing Rate* – DOE's recommended breathing rates are smaller than the activity weighted default breathing rate for the DandD code listed in Table 6.87 of NUREG/CR-5512, Vol. 3. Further, DOE has not provided justification for the applicability of U.S. population survey data from EPA/600/R-09/052F for breathing rate to the average member of the critical group at SRS. DOE should justify a breathing rate based on regional or local characteristics and habits that would be expected to be consistent with the average member of the critical group for SRS PAs.

- *Contaminated Food Fractions* – DOE's recommended fractions of contaminated foods are smaller than the default fractions of contaminated foods for the DandD code listed in Table 6.87 of NUREG/CR-5512, Vol. 3, which conservatively assumes all foods are contaminated. DOE has not provided justification for the applicability of U.S. population survey data from EPA/600/R-09/052F, Table 13-68, for home-produced foods to the average member of the critical group at SRS. For instance, DOE has not provided a justification for selecting total fractions rather than fractions for those who farm, for example, since this value would be more consistent with the exposure pathways evaluated by DOE in the dose methodology. DOE should justify contaminated food fractions for both deterministic and probabilistic modeling based on regional or local characteristics and habits that would be expected to be consistent with the average member of the critical group for SRS PAs.

NRC staff will continue to monitor DOE's human uptake parameters under Monitoring Factor 6.2, "Model and Parameter Support," in the SRS TFs Monitoring Plan (ML15238B403) and Monitoring Factor 10.08, “Consumption Factors and Uncertainty Distributions for Transfer Factors,” in the SDF Monitoring Plan (ML13100A076).

Animal and Livestock Uptake Parameters

Animal uptake parameters identified in Tables 5 and 7 are behavioral. As discussed in NUREG-1854 and NUREG-1573, behavioral parameters should be representative of the average member of the critical group in the modeled exposure scenario and should be based upon regional or local habits and characteristics if these data are available. Generic parameter values found in the literature should be documented as to their applicability to the expected site conditions and an attempt to represent a best estimate of the actual values at the site. A minimum number of sources of generic data should be used to maintain internal consistency. Discussion of NRC staff' review of animal uptake parameters and their supporting justifications follows:

- *Water Consumption by Animals* – While DOE's recommended meat and milk livestock water consumption rates for deterministic modeling are smaller than the rates from RG 1.109, Rev. 1 (ML003740384), Table E-3, and for the DandD code listed in Table 6.87 of NUREG/CR-5512, Vol. 3, DOE has provided justification for the rates based on surveyed agricultural extension agents in the SRS region. DOE's recommended poultry and egg-producing animal water consumption rates for deterministic modeling are consistent with the default rates from Table 6.87 of NUREG/CR-5512, Vol. 3. NRC staff finds that DOE's recommended water consumption rates are acceptable for use in the deterministic modeling for SRS PAs. For probabilistic modeling, DOE recommends ranges that span from the recommended deterministic rate to rates that are consistent with the default rates listed in Table 6.87 of NUREG/CR-5512, Vol. 3, and are consistent with the maximum range recommended for probabilistic modeling in NUREG/CR-5512, Vol. 3. NRC staff finds that DOE's recommended water consumption rates for meat- and milk-producing livestock acceptable for use in the probabilistic modeling for SRS PAs.

- *Fodder Consumption by Animals* – DOE's recommended fodder consumption rates for deterministic modeling are consistent with default values for the DandD code from Table 6.87 of NUREG/CR-5512, Vol. 3 and RG 1.109, Rev. 1 (ML003740384), Table E-3, for milk-producing livestock, poultry, and egg-producing animals[15]. Although, DOE's recommended fodder consumption rate for deterministic modeling is less than the rates recommended in RG 1.109, Rev. 1 (ML003740384), and Table 6.87 of NUREG/CR-5512, Vol. 3, DOE has provided justification for the rate based on surveyed

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[15] Although the fodder consumption rates for poultry and egg-producing animals are somewhat lower than the default values reported in Table 6.87 of NUREG/CR-5512, Vol. 3 (e.g., DOE recommends 0.1 kg/d while Table 6.87 recommends 0.1192 and 0.1385 kg/d for poultry and egg-producers respectively), the difference is not expected to significantly alter the impact of this pathway to overall results of the PAs.

agricultural extension agents in the SRS regions[16]. Therefore, NRC staff finds the fodder consumption rates acceptable for use in the deterministic modeling for SRS PAs. For probabilistic modeling, DOE recommends ranges for fodder consumption by meat- and milk-producing livestock from Table 4-1 of WSRC-STI-2007-00004, Rev. 4 and are reportedly based on standard deviations of 8 kg/d and 11 kg/d for the fodder beef and milk cow consumption rates, respectively. However, it is not clear to NRC staff how the recommended ranges are consistent with the reported standard deviations and from where the reported standard deviations are derived. DOE should clarify its basis for the recommended probabilistic parameter ranges for fodder consumption for meat- and milk-producing livestock for SRS PAs.

- *Soil Consumption by Animals* – DOE's recommended soil consumption rates for deterministic modeling are consistent with default values for the DandD code from Table 6.87 of NUREG/CR-5512, Vol. 3 for poultry and egg-producing animals. Therefore, NRC staff finds the soil consumption rates for poultry and egg-producing animals acceptable for use in the deterministic modeling for SRS PAs.

- *Contaminated Fodder and Soil Fractions* – DOE's recommended contaminated fodder consumption fractions for beef and milk-producing livestock for the deterministic modeling are smaller than the default fractions for the DandD code listed in Table 6.87 of NUREG/CR-5512, Vol. 3, which conservatively assumes all fodder is contaminated. Whereas, for poultry and egg-producing animals, DOE recommends a contaminated fraction for fodder and soil consistent with Table 6.87 of NUREG/CR-5512, Vol. 3. DOE has provided justification for the beef- and milk-producing contaminated fodder fraction for the deterministic modeling based on surveyed agricultural extension agents in the SRS regions which reports that the fractions are consistent with the proportion of fodder derived from pasture grasses as opposed to commercial grain or silage (WSRC-RP-91-17). However, DOE should provide a basis for assuming that the fraction of pasture grass is appropriate for estimating the fraction of livestock fodder contaminated based on regional practices. DOE should also provide a basis for the range of contaminated fractions recommended for the probabilistic modeling for livestock fodder. NRC staff finds the contaminated fractions for poultry and egg-producing animal fodder and soil acceptable for use in the deterministic modeling for SRS PAs.

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[16] DOE also justified the fodder consumption rate for milk-producing livestock based on surveyed county extension agents for the SRS region.

NRC staff will continue to monitor DOE's animal and livestock uptake parameters under Monitoring Factor 6.2, "Model and Parameter Support," in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403). NRC staff is also expanding Monitoring Factor 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors," in the SDF Monitoring Plan (ML13100A076) to include the animal and livestock uptake parameters and will also monitor the animal and livestock uptake parameters under this Monitoring Factor.

Transfer Coefficients for Biotic Accumulation

Transfer coefficients are metabolic parameters. As discussed in NUREG-1854 and NUREG-1573, metabolic parameters should be representative of the average member of the critical group in the modeled exposure scenario and should be based upon regional or local habits and characteristics if these data are available. Generic parameter values found in the literature should be documented as to their applicability to the expected site conditions and an attempt to represent a best estimate of the actual values at the site. In general, a minimum number of sources of generic data should be used to maintain internal consistency, however, for transfer coefficients, there are several compendia of values and associated uncertainty for the transfer of radionuclides through food products. These compendia often represent the only information available to develop transfer coefficients short of site-specific studies.

In the Monitoring Plans for SRS TFs (see Monitoring Factor 6.2, "Model and Parameter Support"; ADAMS Accession No. ML15238B403) and the SDF (see Monitoring Factor 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors"; ADAMS Accession No. ML13100A076), NRC staff identifies issues with DOE's transfer coefficients regarding DOE's treatment of uncertainty. In general, NRC staff finds the transfer coefficients recommended in SRR-CWDA-2013-00058, Rev. 1, which are derived from the hierarchy of reference documents, acceptable for use in the deterministic modeling for SRS PAs, except for the factors noted below. Further, DOE's use of logarithmically-distributed multipliers for the probabilistic modeling is adequate for representing uncertainty in the transfer coefficients for the SRS PAs. However, DOE should improve the clarity of how the distributions were developed and their adequacy for capturing the relevant uncertainty in the supporting references for significant isotopes. NRC staff was not able to independently confirm the development of probabilistic distributions from DOE's descriptions.

- *Soil-to-Plant Transfer Factors* – DOE has developed soil-to-plant transfer factors by weighting transfer factors from IAEA-TRS-472 by estimated percentages of commercially produced plant groups within 50 miles [80 kilometers] of SRS area based on the 2007 U.S. Department of Agriculture (USDA) National Agricultural Statistics (USDA, 2009). The weighting factors used by DOE were 55-percent non-leafy vegetables, 20-percent leafy vegetables, 15-percent legumes, and 10-percent tubers and roots. DOE has not provided a basis that the commercially-produced weightings used to estimate the soil-to-plant transfer coefficients are appropriate for the average member of the critical group.

- *Fodder-to-Milk Transfer Factors* – DOE recommends a value for the deterministic modeling for Tc from the HTF PA, Rev. 1 (SRR-CWDA-2010-00128, Rev. 1). The recommended value is from the HTF PA, Rev. 1 (SRR-CWDA-2010-00128, Rev. 1) because the highest document in the DOE's hierarchy, PNNL-13421, reported a value that is lower than the value used in the HTF PA. While documents in DOE's hierarchy that are lower than PNNL-13421 (i.e., NUREG/CR-5512 and ORNL-5786) report higher values than PNNL-13421, the higher values are not based on actual Tc data. Rather, the values reported in NUREG/CR-5512 and ORNL-5786 are derived from UCRL-51939, which reports a lack of Tc data for milk in animals and bases the Tc value on I because of expected similarities between the chemical properties and behavior of pertechnetate and iodide anions in the body. The value reported in PNNL-13421 is derived from Tc-99m data that is presented in Johnson et al. (1988). The most recent IAEA compendium, IAEA-TRS-472, declined to recommend a value for Tc because of potential variation between Tc-99 and the short-lived gamma-emitting Tc isotopes (e.g., Tc99m) that were used in the studies available in the literature, including Johnson et al. (1988) [see IAEA-TECDOC-1616]. Therefore, DOE should document a justification that the recommended value for deterministic modeling is appropriate or rely upon more conservative values from other references in the hierarchy of documents.

- *Fodder-to-Beef Transfer Factors* – DOE appears to recommend a value for deterministic modeling for Tc from WSRC-STI-2007-00004, Rev. 4 even though sources higher in the hierarchy provide values for Tc that are somewhat larger (up to approximately 1.35 times larger) than the recommended value. The recommended value is from the HTF PA, Rev. 1 (SRR-CWDA-2010-00128, Rev. 1), because the highest document in the DOE's hierarchy that reports a value, PNNL-13421, reported a value that is lower than the value used in the HTF PA, Rev. 1. Other documents lower in the DOE's hierarchy (e.g., ORNL-5786) report larger Tc transfer coefficients than PNNL-13421. The value reported in PNNL-13421 is derived from Bishop et al. (1989), which is a compendium of literature values. However, the most recent IAEA compendium, IAEA-TRS-472, declined to recommend a value for Tc because of potential variation between Tc-99 and the short-lived gamma-emitting Tc isotopes that were used in the available studies, which include Johnson et al. (1988) [see IAEA-TECDOC-1616]. DOE should document a justification that the recommended value for deterministic modeling is appropriate or rely upon more conservative values from other references in the hierarchy of documents.

- *Water-to-Fish Transfer Factors* – For Cm and Np, DOE recommended a fish bioaccumulation value from PNNL-13421 because IAEA-TRS-472 did not recommend a value. However, NUREG/CR-5512, although lower in the hierarchy, was more conservative than PNNL-13421. However, the basis for NUREG/CR-5512 uses Pu as a surrogate because of a lack of Np- and Cm-specific data. Therefore, DOE's use of the value from PNNL-13421 is reasonable. Also, for C and Pu, DOE uses smaller bioaccumulation values than recommended by IAEA-TRS-472. For C, DOE adequately justifies the selected value in Section 3.1.5 of SRNL-STI-2010-00447, Rev. 0 based on an SRS study (Hinton, et al., 2009) of carbon intake in SRS streams. For Pu, DOE argues that the value reported in IAEA-TRS-472, which is several orders of magnitude larger than the DOE-selected value, seems unreasonable based on professional judgment. DOE should use the IAEA-TRS-472 value according to its hierarchy or provide adequate support for the professional judgement that the IAEA-TRS-472 value is too large.

NRC staff will continue to monitor DOE's transfer coefficients under Monitoring Factor 6.2, "Model and Parameter Support," in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) and Monitoring Factor 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors," in the SDF Monitoring Plan (ADAMS Accession No. ML13100A076).

<u>Exposure and Inhalation Parameters</u>

Exposure and Inhalation parameters identified in Table 9 are either behavioral (e.g., times spent performing activities) or physical (e.g., mass loading of soil in air). As discussed in NUREG-1854 and NUREG-1573, behavioral parameters should be representative of the average member of the critical group in the modeled exposure scenario and should be based upon regional or local habits and characteristics if these data are available. Generic parameter values found in the literature should be documented as to their applicability to the expected site conditions and an attempt to represent a best estimate of the actual values at the site. A minimum number of sources of generic data should be used to maintain internal consistency.

DOE has not provided a justification in SRR-CWDA-2013-00058, Rev. 1, for the applicability of U.S. population survey data from EPA/600/R-09/052F to the average member of the critical group for time spent performing activities such as gardening, showering/bathing, and swimming for SRS PAs. For example, DOE limits many exposures to the time spent gardening. However, DOE has not provided a rationale for why the time spent gardening is appropriate considering that some exposure pathways may be viable for other outdoor activities. In this case, Table 6.87 of NUREG/CR-5512, Vol. 3 recommends a higher outdoor time than DOE assumes for gardening. DOE should justify that the time spent gardening is appropriate for representing many of the outdoor exposure pathways for the average member of the critical group. Further, in recommending values for time spent gardening, bathing, swimming, and boating, DOE frequently departs from its reference person definition whose habits and characteristics are based on median habits of the U.S. population and relies upon mean values.

Nonetheless, for many of the other behavioral exposure and inhalation parameters the NRC staff finds the parameter values acceptable for use for the reference person in SRS PAs because the values are more conservative than values derived from regional surveys (e.g., compare DOE's value for time spent swimming to the values reported in WSRC-RP- 91-17 for time spent swimming by a child or adult), or reasonable variations in the values for an average member of the critical group are not expected to significantly impact the results of DOE's PAs (i.e., time spent bathing/showering and the difference between DOE's value for time spent swimming and time spent swimming by a teen from WSRC-RP-91-17). NRC staff also finds both DOE's justification for time spent boating adequate and DOE's assumption of 20 hours for an inadvertent intruder to install a well acceptable for use in SRS PAs.

DOE should provide a basis for the development of probabilistic distribution parameter values for the behavioral exposure and inhalation parameters (i.e., time spent gardening, drilling) to support the adequacy of assumed ranges. For behavioral exposure and inhalation parameter distributions that are based on U.S. population survey data (i.e., time spent bathing/showering, swimming), DOE's development of probabilistic parameters is generally subject to the same concerns raised about the application of U.S. population behaviors to the average member of the critical group. Also, if DOE were to justify the appropriateness of using U.S. population survey data to represent the average member of the critical group for SRS PAs, DOE should provide a basis for the selection of parameter distributions. For example, the basis for the selection of probabilistic distributions developed through trial and error fits to U.S. population survey data from EPA/600/R-09/052F should include goodness-of-fit statistics to U.S. population survey data. DOE should also improve the clarity of how the fit distributions are developed (e.g., what survey values are used to normalize data).

For the physical parameters, DOE relies upon studies of airborne release from free-fall spills of aqueous solutions; values from a Hanford analysis for moisture contents of ambient air and shower air; and mass loading of soil in air while gardening based on literature and an SRS study. While some of DOE's justifications may not be as applicable to these activities[17] at SRS, NRC staff finds the justification adequate for airborne release and moisture content of air while showering, swimming, and boating because any reasonable variation[18] would not be expected to have a significant impact on PA results. Although the mass loading of soil in air while gardening is lower than the default values from Table 3.87 of NUREG/CR-5512, Vol. 3, the

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[17] The velocity of water from a pressurized showerhead is larger than free-fall liquid assessed in DOE-HDBK-3010-94, Vol. I, for example. Also, volatile radionuclides, such as Tc and I, during hot showers would partition to the gaseous phase increasing concentrations in the shower above water particulate concentrations.

[18] For example, multiplying the airborne release fraction and the moisture content from Table 9 suggests that the airborne concentration of water particles would be approximately 4 mg/m^3 during showering. This concentration is comparable to data presented by Zhou et al. (2007) that indicates respirable water particle concentrations ranging from 0.02-0.1 mg/m^3 for cold showers and 5-14 mg/m^3 for hot showers.

values are consistent with an average dust loading measured above two agricultural fields at SRS (Shinn et al., 1982).

NRC staff will continue to monitor DOE's exposure and inhalation parameters under Monitoring Factor 6.2, "Model and Parameter Support," in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403). NRC staff is also expanding Monitoring Factor 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors," in the SDF Monitoring Plan (ML13100A076) to include the exposure and inhalation parameters and will also monitor the exposure and inhalation parameters under this Monitoring Factor.

Soil Parameters

Soil parameters identified in Table 10 are physical parameters. NRC staff finds that DOE provides site-specific justifications for the recommended values for these physical parameters or makes reasonable assumptions; therefore, the recommended values are adequate for modeling in SRS PAs given the significance of these parameters.

Crop and Gardening Parameters

Crop and gardening parameters identified in Table 11 are physical and behavioral parameters. In general, DOE provides site-specific justifications for the recommended values for the physical parameters or makes reasonable assumptions; therefore, the recommended values are adequate for modeling in SRS PAs given the significance of these parameters, except the crop and garden yield. DOE selected a value of 100 m^2 for the area of the garden. However, as noted in Table 11 of this document, using the method described in the basis for the area of the garden (Section 3.4 of WSRC-STI-2007-00004, Rev. 4) and substituting the deterministic parameter values for the produce consumption rate, crop yield, and locally produced fraction from SRR-CWDA-2013-00058, Rev. 1 results in an area of 16 m^2 for the garden. While this smaller garden area would result in larger intruder exposures (because the area of the garden is in the denominator when determining concentrations in the soil from cuttings), NRC staff find the use of 100 m^2 reasonable given that it is a behavioral parameter and consistent with the default value recommended in NUREG/CR-5512, Vol. 3. However, DOE does not clearly identify the basis for the recommended values for the crop yield parameter for the probabilistic modeling. DOE should document the basis for the recommended values for the probabilistic modeling and demonstrate it is consistent with the range of areas expected based upon the rationale used to support the area of the garden.

As discussed in NUREG-1854 and NUREG-1573, behavioral parameters should be representative of the average member of the critical group in the modeled exposure scenario and should be based upon regional or local habits and characteristics if these data are available. In general, DOE provides site-specific justifications for the recommended values for the physical parameters or makes reasonable assumptions; therefore, the recommended values are adequate for modeling in SRS PAs given the significance of these parameters, except for the leafy fraction parameter. DOE justifies the recommended value for the leafy fraction for the deterministic modeling based upon commercially-produced vegetables grown in the SRS region. However, DOE has not justified the representativeness of commercially-produced vegetables for the average member of the critical group. DOE should provide a basis for using the fraction of commercially-produced vegetables for the average member of the critical group.

NRC staff will continue to monitor DOE's crop and gardening parameters under Monitoring Factor 6.2, "Model and Parameter Support," in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403). The NRC staff is also expanding Monitoring Factor 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors," in the SDF Monitoring Plan (ML13100A076) to include the crop and gardening parameters and will also monitor the crop and gardening parameters under this Monitoring Factor.

<u>Drilling Parameters</u>

In general, the drilling parameters are adequate for use in SRS PAs. However, with respect to the probabilistic distribution for the well depth, as previously noted in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) for Monitoring Factor 6.2, "Model and Parameter Support," NRC staff indicated that Gordon Aquifer concentrations should not be used to demonstrate compliance with the performance objectives if higher concentrations are observed in another aquifer that can support groundwater-dependent pathways. NRC staff will continue to monitor DOE's drilling parameters used in the SRS PAs in accordance with the Monitoring Plans.

<u>Sorption Coefficients</u>

DOE has not provided a basis for use of sandy soil sorption coefficients in the biosphere soil buildup model. Further, the NRC staff, in the Monitoring Plans for the SRS TFs (ADAMS Accession No. ML15238B403) and SDF (ADAMS Accession No. ML13100A076), identifies several issues with DOE's justification for K_d values used for modeling transport in the subsurface and the biosphere. See Monitoring Factor 6.2, "Model and Parameter Support," in the SRS TFs Monitoring Plan and Monitoring Factors 7.01, "Certain Risk-Significant K_d Values in Site Sand and Clay;" 10.07, "Calculation of Build-Up in Biosphere Soil;" and 10.09, "K_d Values for SRS Soil," in the SDF Monitoring Plan. DOE has not addressed the issues presented in the Monitoring Factors in the revised dose methodology. NRC staff will continue to monitor DOE's justification for K_d values used in the SRS PAs in accordance with the Monitoring Plans.

<u>Follow-up Actions</u>

There are no Follow-up Actions related to the DOE biosphere dose methodology for the FTF, HTF, and SDF at SRS.

Open Issues

There are no Open Issues related to the DOE biosphere dose methodology for the FTF, HTF, and SDF at SRS.

Conclusions

As a result of the review of several DOE documents that support the Revised Dose Methodology (SRR-CWDA-2013-00058, Rev. 1), the NRC staff concludes that the Revised Dose Methodology generally provides a transparent and traceable documentation of the human receptor definitions, exposure pathways, dose calculations, and parameter values and distributions. Further the methodology includes an all-pathways exposure scenario that is widely used in PAs and is well-suited for the purpose. DOE's calculations are well documented and appropriate for the purpose. However, the NRC staff has identified the need for additional justification with respect to DOE's human receptor definition and its relevance for the recommendation of parameter values and distributions and the basis for the recommendation of several parameter values and distributions identified herein. To reach these conclusions, the NRC staff focused on a number of areas listed in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) related to Monitoring Factors 4.1, "Natural Attenuation of Key Radionuclides," and 6.2, "Model and Parameter Support," and in the SDF Monitoring Plan (ADAMS Accession No. ML13100A076) related to Monitoring Factors, 7.01, "Certain Risk-Significant K_d Values in Site Sand and Clay;"" 10.07, "Calculation of Build-Up in Biosphere Soil;" 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors;" and 10.09, "K_d Values for SRS Soil".

With respect to DOE's human receptor definition, NRC staff has concerns with DOE's receptor, the reference person, because it differs from the average member of the critical group concept. The average member of the critical group concept entails an assessment of the more highly exposed individuals in the population, who may have different characteristics than the U.S. population as a whole, whose characteristics DOE has tended to rely upon to define its receptor. NRC staff will continue to monitor DOE's human receptor definition under Monitoring Factor 6.2, "Model and Parameter Support," in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) and Monitoring Factor 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors," in the SDF Monitoring Plan (ADAMS Accession No. ML13100A076).

NRC staff's concern with the human receptor definition also resulted in concerns with recommended values for several parameters that quantify the receptor's behavior including certain consumption rates, the breathing rate, the fractions of foods produced locally, certain exposure and inhalation parameters, and certain crop and gardening parameters. NRC staff will continue to monitor DOE's behavioral parameters and their applicability to the average member of the critical group under Monitoring Factor 6.2, "Model and Parameter Support," in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) and Monitoring Factor 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors," in the SDF Monitoring Plan (ADAMS Accession No. ML13100A076).

NRC staff also identified concerns with the transparency and traceability of parameter value recommendations other than those summarized above and their supporting basis. These parameters include certain animal uptake parameters, transfer coefficients, exposure and inhalation parameters, and drilling parameters that are identified herein. NRC staff will continue to monitor DOE's recommended parameter values and their supporting basis for these identified parameters under Monitoring Factor 6.2, "Model and Parameter Support," in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) and Monitoring Factor 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors," in the SDF Monitoring Plan (ADAMS Accession No. ML13100A076).

Finally, NRC staff also noted that issues regarding DOE's selection of sorption coefficients are also relevant to the Revised Dose Methodology. NRC has identified that these issues will continue to be monitored under Monitoring Factor 4.1, "Natural Attenuation of Key Radionuclides," listed in NRC staff's SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) and Monitoring Factors 7.01, "Certain Risk-Significant K_d Values in Site Sand and Clay;" 10.07, "Calculation of Build-Up in Biosphere Soil;" and 10.09, "K_d Values for SRS Soil," listed in NRC staff's SDF Monitoring Plan (ADAMS Accession No. ML13100A076).

As a result of its review of DOE's Revised Dose Methodology (SRR-CWDA-2013-00058, Rev. 1), NRC staff has identified the following items that should be addressed in future SRS PA revisions:

- DOE should provide additional justification that the reference person is equivalent to the average member of the critical group used to demonstrate that the 10 CFR Part 61 performance objectives are met.

- DOE should provide a basis to support the use of median U.S. population survey data in lieu of characteristics of the average member of the critical group or rely on characteristics associated with the 95th percentile of survey distributions to ensure a cautious approach.

- DOE should provide a technical basis for the use of inhalation dose coefficients associated with an appropriate lung absorption type or, in the absence of a technical basis, should recommend the dose coefficients associated with a lung absorption type that are most conservative.

- DOE should provide a justification for the applicability of U.S. population survey data from EPA/600/R-09/052F to the average member of the critical group for human consumption parameters in SRS PAs. Specifically, DOE should justify:

    - Contaminated water consumption rate based on regional or local characteristics and habits that would be expected to be consistent with the average member of the critical group for SRS PAs;

    - Milk consumption rate based on regional or local characteristics and habits that would be expected to be consistent with the average member of the critical group for SRS PAs;

    - Poultry and egg consumption rates based on regional or local characteristics and habits that would be expected to be consistent with the average member of the critical group for SRS PAs;

    - Fish consumption rate based on regional or local characteristics and habits that would be expected to be consistent with the average member of the critical group for SRS PAs;

    - Breathing rate based on regional or local characteristics and habits that would be expected to be consistent with the average member of the critical group for SRS PAs; and

    - Contaminated food fractions for both deterministic and probabilistic modeling based on regional or local characteristics and habits that would be expected to be consistent with the average member of the critical group for SRS PAs.

- DOE should provide a basis for the selection of parameter distributions and goodness-of-fit statistics for selected probabilistic distributions for human consumption parameters that were developed through trial and error fits to U.S. population survey data from EPA/600/R-09/052F. DOE should also improve the clarity of how the distributions are developed.

- DOE should provide a basis for assuming that the fraction of pasture grass is appropriate for estimating the fraction of livestock fodder contaminated based on regional practices. DOE should also provide a basis for the range of contaminated fractions recommended for the probabilistic modeling for livestock fodder.

- DOE should clarify its basis for the recommended probabilistic parameter ranges for fodder consumption for meat- and milk-producing livestock for SRS PAs.

- DOE should improve the clarity of how the transfer factor probabilistic distributions were developed and their adequacy for capturing the relevant uncertainty in the supporting references for significant isotopes.
- DOE has not provided a basis that the commercially-produced weightings used to estimate the soil-to-plant transfer coefficients are appropriate for the average member of the critical group.
- DOE should document justifications that the recommended values for both fodder-to-milk and -beef transfer factors used in the deterministic modeling are appropriate or rely upon more conservative values from other references in the hierarchy of documents.
- DOE should use the IAEA-TRS-472 value for the water-to-fish transfer factor according to its hierarchy or provide adequate support for the professional judgement that the IAEA-TRS-472 value is too large.
- DOE should justify that the time spent gardening is appropriate for representing many of the outdoor exposure pathways for the average member of the critical group.
- DOE should document the basis for the recommended values for crop yield used in the probabilistic modeling and demonstrate they are consistent with the range of areas expected based upon the rationale used to support the area of the garden.
- DOE should provide a basis for using the fraction of commercially-produced vegetables for the average member of the critical group.

Some of the items identified above have previously been documented by NRC under either Monitoring Factor 6.2, “Model and Parameter Support,” in the SRS TFs Monitoring Plan (ADAMS Accession No. ML15238B403) or Monitoring Factor 10.08, “Consumption Factors and Uncertainty Distributions for Transfer Factors,” in the SDF Monitoring Plan (ADAMS Accession No. ML13100A076). As a result of this review, the NRC staff is expanding Monitoring Factor 6.2 for the SRS TFs and Monitoring Factor 10.08 for the SDF to include the items identified above that were not previously documented.

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