Technical Review: Dose and Exposure Pathways Model for the U.S. Department of Energy 2020 Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site

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Reviewer

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1.0 Purpose and Scope

The purpose of this U.S. Nuclear Regulatory Commission (NRC) staff Technical Review Report (TRR) is to document the NRC staff review of the U.S. Department of Energy (DOE) Dose and Exposure Pathways Model (referred to herein as the "DOE Dose Model") for the DOE 2020 Performance Assessment (PA) for the Saltstone Disposal Facility (SDF) at the Savannah River Site (SRS). The NRC staff performed this review to support a future decision about whether the DOE has demonstrated that radioactive waste disposal activities at the SDF comply with the performance objectives of Title 10 of the *Code of Federal Regulations* (10 CFR), Part 61.

This review also supports NRC monitoring of the SDF under the NRC document *Plan for Monitoring Disposal Actions Taken by the U.S. Department of Energy at the Savannah River Site Saltstone Disposal Facility in Accordance with the National Defense Authorization Act for Fiscal Year 2005, Revision 1* (available in the NRC Agencywide Documents Access and Management System [ADAMS] Accession No. ML13100A113) (referred to as the "NRC SDF Monitoring Plan" or "Monitoring Plan" in this document). Specifically, this TRR supports NRC monitoring under Monitoring Factor (MF) 10.07, "Calculation of Build-Up in Biosphere Soil" and MF 10.08 "Consumption Factors and Uncertainty Distributions for Transfer Factors." In addition, the NRC staff supplemented MF 10.08 in a previous TRR (ADAMS Accession No. ML16277A060). The NRC staff will use insights from this technical review to update the Monitoring Plan. In this TRR, the NRC staff has included recommended additions to the Monitoring Plan in italics in the NRC Evaluation (Section 4) and summarized those additions in the Conclusions (Section 7). The staff also has numbered those recommendations (e.g., DEPM-01, DEPM-02) to facilitate cross referencing in a future Technical Evaluation Report and a revised Monitoring Plan.

The NRC staff reviewed the modeling parameters and equations the DOE used in the Dose Model for the 2020 SDF PA (SRR-CWDA-2019-00001). The review scope included aspects of the Dose Model that affect the projected dose to hypothetical members of the public at two locations: (1) 100 meters (m) from the SDF boundary and (2) the nearest contaminated streams[1]. The NRC staff will compare the projected dose to a member of the public at those locations to the 0.25 millisievert (mSv) (25 millirem [mrem]) dose limit under 10 CFR Section 61.41, "Protection of the general population from releases of radioactivity." The review scope includes aspects of the model that affect a member of the public that could also

[1] For each modeled year, the DOE chose either McQueen Branch or Upper Three Runs, depending on which had the greater radionuclide concentrations in the groundwater where groundwater seeped into the stream.

affect the projected dose to an individual who inadvertently intrudes into the SDF 100 years or more after site closure (referred to as an "inadvertent intruder" in this document). However, aspects of the Dose Model that only affect an inadvertent intruder (e.g., inhalation of suspended soil while drilling a well) are addressed in a separate TRR. In this document, the NRC staff uses the term "human receptor" for consistency with the term the DOE used in the 2020 SDF PA when it is not necessary to distinguish between a member of the public and an inadvertent intruder.

2.0 Background

Because the SDF and the SRS Tank Farms (i.e., H-Tank Farm and F-Tank Farm) are both located at the SRS, the Dose Models for those facilities share technical bases. The DOE provided those technical bases in the DOE document *Dose Calculation Methodology for Liquid Waste Performance Assessments at the Savannah River Site* (SRR-CWDA-2013-00058), which has had three revisions. The NRC staff reviewed the first version (i.e., Revision [Rev.] 0) of that document as part of its review of the DOE Fiscal Year 2013 Special Analysis for the SDF (SRR-CWDA-2013-00062). The NRC staff reviewed Rev. 1 of SRR-CWDA-2013-00058 in a previous TRR (ADAMS Accession No. ML16277A060) (referred to in this document as the "2016 Biosphere TRR"). For aspects of the model that the DOE did not change from the version documented in SRR-CWDA-2013-00058, Rev. 1, this TRR relies on findings of the 2016 Biosphere TRR. The DOE based the Dose Model for the 2020 SDF PA on Rev. 2 of SRR-CWDA-2013-00058, which the DOE issued in January 2019. References to SRR-CWDA-2013-00058 in this TRR indicate Rev. 2 of that document, unless otherwise specified.

The NRC SDF Monitoring Plan does not include a Monitoring Area (MA) for biosphere. Instead, it groups MFs related to Dose Modeling under MA 10, "Performance Assessment Model Revisions". Monitoring Area 10 includes two MF related to the Dose Model: (1) MF 10.07, "Calculation of Build-Up in Biosphere Soil" relates to the sorption coefficients the DOE used to model radionuclide buildup in soil irrigated with contaminated groundwater; and (2) MF 10.08, "Consumption Factors and Uncertainty Distributions for Transfer Factors." Originally, MF 10.08 only addressed human intake factors (e.g., water ingestion, volume of air inhaled) and the uncertainty in transfer factors (e.g., soil-to-plant, water-to-fish). In the 2016 Biosphere TRR, the NRC staff supplemented MF 10.08 to include monitoring of how well human ingestion rates, local fractions of produce and animal feed, and dose coefficients represented the average member of the critical group. In addition, in that TRR, the NRC staff supplemented MF 10.08 to include technical support for certain stochastic distributions used in the probabilistic model. This TRR addresses specific issues raised in the 2016 TRR in the applicable section for each parameter.

Further details about MF 10.07 and MF 10.08 are provided in the NRC SDF Monitoring Plan and the 2016 Biosphere TRR. This TRR addresses the sub-topics of the MFs in the related sub-sections of Sections 3 and 4.

3.0 DOE Dose and Exposure Pathways Model for the 2020 SDF PA

3.1 Overview

The DOE Dose Model for the 2020 SDF PA takes groundwater concentrations of radionuclides as input and represents transfers of those radionuclides from the groundwater, through the food chain, and to a human receptor. The DOE selected exposure pathways based on the definition

of the critical group as an adult subsistence farmer at or near the SRS. The DOE assumed a human receptor would live near the SDF, get drinking water from a well 100 meters (m) from the SDF or from a local creek, grow crops, raise livestock, and participate in water recreation including boating, swimming, and fishing. To represent the "average member" of the critical group, in most cases the DOE used the mean or median of applicable ranges of values (i.e., rather than an upper percentile of the range) as the basis for deterministic Compliance Case parameters. In some cases, the DOE adjusted the mean or median values to account for the location or occupation (i.e., agricultural) of a member of the critical group.

The Dose Model has three main components. It uses transfer factors to represent the transfer of radionuclides between different environmental media (e.g., soil, water, plants, animals). It uses intake parameters to model the ingestion and inhalation of contaminated substances by humans and livestock, and occupancy and geometric parameters to model direct exposure of humans to radioactivity. Finally, it uses dose conversion factors (DCFs) to calculate the projected dose from the inhalation of, ingestion of, and direct exposure to radionuclides.

In deterministic analyses, the DOE modeled three cases as part of its "Central Scenario": the "Realistic Case," "Compliance Case," and "Pessimistic Case." The DOE described the Realistic Case as its "best estimate" of the projected dose. The DOE described the "Compliance Case" as more easily defensible than the realistic values and used the Compliance Case results to demonstrate compliance with the 10 CFR Part 61 performance objectives. Finally, the DOE described the "Pessimistic Case" as based on parameter values that are biased toward increasing dose results and maximizing defensibility. For some parameters, the DOE also used the terms "Realistic Input," "Recommended Input," and "Conservative Input," for use in the Realistic, Compliance, and Pessimistic Cases, respectively. Throughout this TRR, the NRC staff used the terms "Realistic," "Compliance," "Recommended," "Pessimistic," and "Conservative" when describing the DOE values to facilitate comparison with cited DOE tables and figures. The use of those terms does not reflect the NRC staff judgment.

In addition to the deterministic parameter values, the DOE also developed stochastic distributions for some parameter values for use in a probabilistic Dose Model. The DOE used the probabilistic model to provide risk insights for the 2020 SDF PA.

3.2 Critical Group and Exposure Pathways

3.2.1 Critical Group

The 2020 SDF PA indicates that the DOE chose exposure pathways and parameter values to project the dose to the average member of the critical group. In *Guidance for Conducting Technical Analyses for 10 CFR Part 61: Draft Report for Comment* (referred to in this document as NUREG-2175) (ADAMS Accession No. ML14357A072), the NRC defines the critical group as "a group of individuals reasonably expected to receive the greatest exposure to releases over time, given the circumstances under which the analysis would be carried out." For the 2020 SDF PA, the DOE document SRR-CWDA-2013-00058 states: "Therefore, the human receptor shall be defined as a hypothetical member of the public who is a gender-weighted, age-weighted adult with the average habits of a subsistence farmer in the approximate vicinity of [SRS]."

The 2020 SDF PA provides projected doses for four human receptors: (1) a member of the public who lives near the SDF and uses water from a well 100 m from the SDF, (2) a member of the public who uses water from McQueen Branch or Upper Three Runs for domestic and

agricultural purposes, (3) an inadvertent intruder who receives an acute dose by drilling into contaminated soil near a disposal structure, and (4) an inadvertent intruder who receives a chronic dose by living on a site after intrusion. As indicated in Section 1.0, above, this TRR addresses biosphere modeling related to the first two of those receptors (i.e., members of the public at different locations). The DOE used the higher of the two projected doses for those hypothetical members of the public to assess compliance with the 10 CFR Section 61.41 performance objective for "Protection of the General Population from Releases of Radioactivity". Most aspects of this review also apply to an inadvertent intruder (e.g., transfer factors, intake rates, DCFs). Differences between the biosphere review in this TRR and the review for an inadvertent intruder will be addressed specifically in a TRR on inadvertent intrusion (ML23017A085).

3.2.2 Exposure Pathways

In the 2020 SDF PA, the DOE assumed a member of the public would only receive dose from secondary sources of contamination and would not directly encounter saltstone itself. The 2020 SDF PA model projects that saltstone will release radionuclides into groundwater and that groundwater will supply water to a well 100 m from the disposal site and to streams onsite. The only difference between the two hypothetical members of the public listed in Section 3.2.1 is the source of water for domestic and agricultural use. A member of the public 100 m from the SDF uses groundwater for drinking, bathing, irrigation, and livestock, and stream water for boating, fishing, and swimming. A member of the public at the stream is assumed to be exposed to contaminated stream water that has the same radionuclide concentrations as groundwater at the seepline for all those purposes. That is, the model does not include the effects of dilution in the stream and assumes the stream has the same radionuclide concentrations as groundwater at the seepline.

In the DOE conceptual model, contaminated water used for irrigation contaminates crops and soil in the irrigated area. The DOE also assumes livestock drink contaminated water and eat fodder grown on the contaminated soil.

Based on those secondary sources of radionuclides, the DOE assumed the member of the public would receive a dose through the following exposure pathways:

- direct radiation:
    - soil while irrigating crops
    - groundwater or stream water while showering
    - stream water while swimming, boating, and fishing

- inhalation:
    - suspended soil
    - suspended groundwater or stream water while showering
    - suspended groundwater or stream water irrigating crops
    - suspended stream water while swimming

- ingestion:
    - groundwater or stream water used for drinking water
    - soil contaminated by irrigation (incidental ingestion)
    - produce irrigated with contaminated groundwater or stream water
    - animal products (i.e., milk, meat, poultry, eggs) from animals that drink contaminated groundwater or stream water and eat feed irrigated with contaminated groundwater or stream water
    - fish from a contaminated stream

The NRC staff reviewed the equations the DOE used to model those exposure pathways in the 2016 Biosphere TRR. Because the DOE did not change the equations for those pathways since that review, the NRC staff did not repeat the equations in this TRR.

The DOE modeled the dose from direct radiation as the product of the radionuclide concentration, the time the human receptor would be exposed to the radiation, and the radionuclide specific DCF. For exposure to contaminated soil, the DOE used a DCF for direct radiation from soil contaminated to 15 centimeters (cm) depth. For direct exposure to contaminated water during swimming or showering, the DOE used DCFs for submersion in water. For boating and fishing, the DOE modified the water submersion DCF with a geometry factor of 0.5 to account for the body not being submerged.

The DOE modeled the dose to a member of the public from ingestion as the product of the radionuclide concentrations in the ingested products, the amount of each product a human receptor ingests in a year, and an ingestion DCF. To determine the amount of a contaminated product a member of the public would consume each year, the DOE multiplied the expected annual consumption by a fraction the DOE determined would be produced locally. For example, to model produce consumption, the DOE determined how much produce a person is expected to consume in a year and then multiplied that annual intake by the fraction produce consumed that is produced locally for households who farm. This TRR addresses that calculation further in Section 3.5.1.

The DOE modeled radionuclide concentrations in water outside of the Dose Model. The DOE modeled radionuclide concentrations in soil with a buildup (accumulation) model that considered sorption of radionuclides onto soil from application of contaminated irrigation water for 25 years. The buildup model included radioactive decay and did not include ingrowth or weathering of soil. The DOE modeled the concentration of radionuclides in plants from two sources: deposition from application of irrigation water (i.e., contaminated ground or surface water) and root uptake from contaminated soil. The DOE deposition model accounted for a fraction of radionuclides in irrigation water being deposited onto plants and then being removed by radioactive decay and weathering. The DOE modeled root uptake with soil-to-plant transfer factors.

The DOE used the concentrations in water, soil, and plants to model the radionuclide concentrations in animal products. The DOE assumed that terrestrial meat and milk animals would ingest radionuclides from contaminated water and from feed (i.e., plants) grown in contaminated soil. The DOE assumed that poultry for meat and eggs would consume contaminated feed (i.e., plants) and soil. The DOE determined the concentrations in meat, milk, poultry, and eggs by multiplying the total amount of radionuclides ingested in water, plants, and soil (as applicable) by the appropriate transfer factor (i.e., feed-to-meat, feed-to-milk, feed-to-poultry, and feed-to-egg). The DOE modeled the concentrations of radionuclides in fish as the product of the concentrations of radionuclides in stream water modeled with radionuclide concentrations in groundwater at the stream seepline and the water-to-fish transfer factors.

The DOE modeled the dose from inhalation as the sum of the dose from inhaling:

- suspended soil while working in a crop or garden
- suspended water while irrigating crops
- suspended water while swimming
- suspended water while showering

In each case, the modeled dose from inhalation as the product of the concentration of suspended soil or water in the air, the radionuclide concentrations on the suspended soil or in the water, an annual average inhalation rate, and the fraction of time during the year the human receptor participated in each activity. The DOE modeled the concentration of suspended soil in the air with a mass loading factor applicable to gardening. The DOE modeled the concentration of water suspended in the air as the product of an air moisture content and a unitless airborne release fraction (ARF).

3.3 Transfer Factors

The DOE Dose Model for the 2020 SDF PA used transfer factors to model the movement of radionuclides between the following environmental media:

- soil-to-plant
- feed-to-meat
- feed-to-milk
- feed-to-poultry
- feed-to-egg
- water-to-fish

The DOE used the same hierarchy of documents to find values for the transfer factors to support the 2020 SDF PA that it used in previous revisions of the Dose Model:

- International Atomic Energy Agency's (IAEA) Technical Report Series No. 472 (IAEA-TRS-472)
- Pacific Northwest National Laboratory's (PNNL) Compendium of Transfer Factors (PNNL-13421)
- Oak Ridge National Laboratory (ORNL) Compendium of Parameters for Transport through Agriculture (ORNL-5786)
- NRC Parameter Analysis for Translating Residual Radioactivity to Dose (NUREG/CR-5512, Vol. 3) (ADAMS Accession No. ML082460902)
- SRS Human Health Parameter Update for PAs (WSRC-STI-2007-00004, Rev. 4), and
- H-Tank Farm PA, Rev. 1 (SRR-CWDA-2010-00128, Rev. 1)

When documents in the hierarchy provided stochastic distributions and did not provide recommended deterministic values, the DOE used the mean of the recommended distribution for the deterministic value. For the soil-to-plant transfer factors, when a document in the hierarchy provided different values for different soil types, the DOE used the value for "all soils." Soil-to-plant transfer factors also considered crop type as discussed in the following section. Because the DOE used the same document hierarchy to support the 2020 SDF PA, the values of most of the transfer factors the DOE used in the 2020 SDF PA are the same as the values the NRC staff reviewed in the 2016 Biosphere TRR. The main exceptions are the soil-to-plant transfer factors, which changed because the DOE updated assumptions about the types of

plants a human receptor near the SDF would ingest. A small number of additional factors changed; those factors are addressed at the end of this section.

The DOE used the transfer factors in Table 1 for each of the cases in the Central Scenario (i.e., the Realistic Case, Compliance Case, and Pessimistic Case). Transfer factors depend on the chemical properties of each element, rather than the radiological properties of each radionuclide. In this TRR, the NRC staff used the element name when providing values specific to an element, and abbreviations for radionuclides (e.g., iodine-129 [I-129]) when referring to specific radionuclides.

Soil-to-Plant Transfer Factors
Most literature values for radionuclide uptake by plant roots provides transfer factors for specific types of plants (e.g., soil-to-leafy greens, soil-to-grain). In contrast, the DOE Dose Model implements soil-to-plant transfer factors with one value for each radionuclide representing all plants. Therefore, to develop soil-to-plant factors to use in the 2020 SDF PA, the DOE weighted literature values for specific types of plants by an assumed distribution of different types of plants. In SRR-CWDA-2013-00058, Rev. 1, the DOE used the distribution of plants grown commercially within 50 miles (80 kilometers) of SRS as the basis for the types of plants a member of the critical group would grow. In the 2016 Biosphere TRR, the NRC staff recommended that the DOE should provide a technical basis for using the relative amounts of commercial crops to model the relative amounts of crops that would be grown and consumed locally by a person engaging in agricultural activities onsite. In the 2020 SDF PA, the DOE revised the relative amounts of different plant types that would be grown and consumed locally based on information in the DOE document, *Recommended Yield Percentage of Locally Grown Produce in the Savannah River Site Area for Use in Dose Calculations to Support Liquid Waste Performance Assessments* (SRR-CWDA-2018-00057). Table 2, below, shows the distribution of plants the DOE used to develop the soil-to-plant transfer factors for the 2020 SDF PA.

The DOE modeled human intake of produce based on the fresh or “wet weight” of plants ingested. Therefore, to be consistent with the modeled human intake of plants, when a reference document provided transfer factors based on the dry weight of a plant, the DOE converted the dry weight transfer factor to a wet weight transfer factor to be consistent with the ingestion rates.

Soil-to-plant transfer factors decreased from the values the NRC reviewed in 2016 for only five elements: actinium, californium, cobalt, iodine, and protactinium. All others stayed the same or increased. The soil-to-plant factor for iodine decreased to 60 percent of the value the NRC reviewed in 2016, which was the largest decrease for any element. The largest increase was for copper, which increased to 470 percent the 2016 value. The soil-to-plant factor for technetium in the 2020 SDF PA was essentially the same as the value the NRC staff reviewed in the 2016 Biosphere TRR (i.e., 103 percent of the 2016 value).

Table 1. Radionuclide transfer factors (adapted from Table 4.4-113 in the 2020 SDF PA)

Element	Soil-to-Plant (unitless)	Feed-to-				Water-to-Fish (L/kg)
		Meat (yr/kg)	Milk (yr/L)	Poultry (yr/kg)	Egg (yr/kg)	
Actinium	5.85×10^{-5}	1.10×10^{-6}	5.48×10^{-8}	1.64×10^{-5}	1.10×10^{-5}	2.50×10^{1}
Aluminum	3.04×10^{-4}	4.11×10^{-6}	5.64×10^{-7}	1.00×10^{-20}	1.00×10^{-20}	5.10×10^{1}
Americium	1.08×10^{-5}	1.37×10^{-6}	1.15×10^{-9}	1.64×10^{-5}	8.21×10^{-6}	2.40×10^{2}
Carbon	2.40×10^{-1}	8.49×10^{-5}	3.29×10^{-5}	1.00×10^{-20}	1.00×10^{-20}	3.00×10^{0}
Californium	5.85×10^{-5}	1.10×10^{-7}	4.11×10^{-9}	1.64×10^{-5}	1.10×10^{-5}	2.50×10^{1}
Chlorine	1.05×10^{1}	4.65×10^{-5}	4.65×10^{-5}	8.21×10^{-5}	7.39×10^{-3}	4.70×10^{1}
Curium	1.72×10^{-4}	1.10×10^{-7}	5.48×10^{-8}	1.64×10^{-5}	1.10×10^{-5}	3.00×10^{1}
Cobalt	2.18×10^{-2}	1.18×10^{-6}	3.01×10^{-7}	2.66×10^{-3}	9.03×10^{-5}	7.60×10^{1}
Cesium	1.16×10^{-2}	6.02×10^{-5}	1.26×10^{-5}	7.39×10^{-3}	1.10×10^{-3}	2.50×10^{3}
Europium	6.85×10^{-3}	5.48×10^{-8}	8.21×10^{-8}	5.48×10^{-6}	1.10×10^{-7}	1.30×10^{2}
Hydrogen	1.15×10^{0}	1.00×10^{-20}	4.11×10^{-5}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{0}
Iodine	6.39×10^{-3}	1.83×10^{-5}	1.48×10^{-5}	2.38×10^{-5}	6.57×10^{-3}	3.00×10^{1}
Potassium	5.82×10^{-1}	5.48×10^{-5}	1.97×10^{-5}	1.10×10^{-3}	2.74×10^{-3}	3.20×10^{3}
Niobium	4.63×10^{-3}	7.12×10^{-10}	1.12×10^{-9}	8.21×10^{-7}	2.74×10^{-6}	3.00×10^{2}
Nickel	3.16×10^{-2}	1.37×10^{-5}	2.60×10^{-6}	2.74×10^{-6}	2.74×10^{-4}	2.10×10^{1}
Neptunium	4.05×10^{-3}	2.74×10^{-6}	1.37×10^{-8}	1.64×10^{-5}	1.10×10^{-5}	2.10×10^{1}
Protactinium	5.85×10^{-5}	1.10×10^{-7}	1.37×10^{-8}	1.64×10^{-5}	1.10×10^{-5}	1.00×10^{1}
Lead	6.60×10^{-3}	1.92×10^{-6}	5.20×10^{-7}	2.19×10^{-3}	2.74×10^{-3}	2.50×10^{1}
Platinum	9.08×10^{-3}	1.10×10^{-5}	1.41×10^{-5}	1.00×10^{-20}	1.00×10^{-20}	3.50×10^{1}
Plutonium	2.46×10^{-5}	3.01×10^{-9}	2.74×10^{-8}	8.21×10^{-6}	3.29×10^{-6}	2.10×10^{4}
Radium	1.03×10^{-2}	4.65×10^{-6}	1.04×10^{-6}	8.21×10^{-5}	8.49×10^{-4}	4.00×10^{0}
Radon	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	7.55×10^{-10}
Samarium	6.85×10^{-3}	5.48×10^{-8}	8.21×10^{-8}	5.48×10^{-6}	1.10×10^{-7}	3.00×10^{1}
Selenium	6.23×10^{-2}	4.11×10^{-5}	1.10×10^{-5}	2.66×10^{-2}	4.38×10^{-2}	6.00×10^{3}
Silver	1.48×10^{-4}	8.21×10^{-6}	1.37×10^{-7}	5.48×10^{-3}	1.37×10^{-3}	1.10×10^{2}
Tin	3.12×10^{-3}	2.19×10^{-4}	2.74×10^{-6}	2.19×10^{-3}	2.74×10^{-3}	3.00×10^{3}
Strontium	1.90×10^{-1}	3.56×10^{-6}	3.56×10^{-6}	5.48×10^{-5}	9.58×10^{-4}	2.90×10^{0}
Technetium	1.17×10^{1}	2.74×10^{-7}	3.83×10^{-7}	8.21×10^{-5}	8.21×10^{-3}	2.00×10^{1}
Thorium	4.31×10^{-4}	6.30×10^{-7}	1.37×10^{-8}	1.64×10^{-5}	1.10×10^{-5}	6.00×10^{0}
Uranium	4.10×10^{-3}	1.07×10^{-6}	4.93×10^{-6}	2.05×10^{-3}	3.01×10^{-3}	9.60×10^{-1}
Zirconium	8.26×10^{-4}	3.29×10^{-9}	9.86×10^{-9}	1.64×10^{-7}	5.48×10^{-7}	2.20×10^{1}

Table 2. Assumed crop yield percentages (Table BIO-1.1 in SRR-CWDA-2021-00047)

Produce	Yield (%)	DOE Reference
Leafy Vegetables	22.2	NUREG/CR-5512, Vol. 1
Legumes	15.0	SRNL-STI-2010-00447
Tubers and Roots	10.0	SRNL-STI-2010-00447
Fruit	22.2	NUREG/CR-5512, Vol. 1
Grain	11.1	NUREG/CR-5512, Vol. 1
Other Vegetables	19.5	Determined by Subtraction from 100%

Table 3. Dry-to-Wet conversion factors used to develop soil-to-plant transfer factors used in the 2020 SDF PA (adapted from Table BIO-2.1 of SRR-CWDA-2021-00047)

Plant Type	Dry-to-Wet Conversion Factor
Leafy vegetables	0.20
Other vegetables	0.25
Other root vegetables	0.25
Fruit	0.18
Grain	0.91

Other Transfer Factors

Aside from the soil-to-plant factors, six transfer factors changed from the values the NRC reviewed in the 2016 Biosphere TRR. Those six included three that the NRC staff specifically addressed in the 2016 Biosphere TRR and three transfer factors for less risk-significant radionuclides (i.e., protactinium, samarium, and silver). The three transfer factors the NRC staff addressed in the 2016 Biosphere TRR were the feed-to-milk and feed-to-meat transfer factors for technetium and the water-to-fish factor for plutonium.

For the feed-to-milk and the feed-to-meat transfer factor for technetium, the 2016 Biosphere TRR indicated that the DOE appeared to have used a value from one of the reference documents out of the order given in the document hierarchy. For the water-to-fish factor for plutonium, the 2016 Biosphere TRR indicated that the DOE should provide additional justification for using a value from one of the reference documents out of the order given in the document hierarchy. In the 2020 SDF PA, the feed-to-meat transfer factor for technetium decreased by a factor of 63, the feed-to-milk transfer factor for technetium decreased by a factor of 13, and the water-to-fish transfer factor increased by a factor of 700.

Stochastic Distributions

In the 2020 SDF PA, the DOE only represented the transfer factors with deterministic values. However, based on the projected doses of Technetium-99 (Tc-99) and I-129 in the 2020 SDF PA[2] and the contributions to those doses from the plant and fish ingestion pathways, the NRC staff requested additional information about the plant and fish transfer factors for technetium and iodine (ADAMS Accession No. ML 21062A217). The DOE provided a revised probabilistic assessment that included probabilistic multipliers for the soil-to-plant and water-to-fish transfer coefficients for iodine and technetium (SRR-CWDA-2021-00047). The DOE identified two references that provided stochastic distributions for transfer factors: IAEA-TRS-472, which is the first document in the transfer factor reference hierarchy listed above, and the Yucca Mountain Project Dose Model Report (MDL-MGR-MD-000001). For the stochastic distributions,

[2] All other radionuclides combined contributed less than 0.1 percent of the projected dose to a member of the public.

the DOE weighted distributions from those two documents equally. Therefore, to combine the recommendations, the DOE added distribution from both sources to a revised version of the probabilistic GoldSim model the DOE used to respond to the NRC staff Request for Supplemental Information (ADAMS Accession No. ML20254A003) and allowed GoldSim to select from each distribution in 50 percent of the realizations. Table 4 provides the distributions the DOE used for the water-to-fish transfer factors.

Table 4. Water-to-fish transfer factors for I-129 and Tc-99 (adapted from Table BIO-3.3 in SRR-CWDA-2021-00047)

Radionuclide	Geometric Mean (L/kg)	Geometric Standard Deviation (L/kg)	Minimum (L/kg)	Maximum (L/kg)	Reference
I-129	30	2.5	11	400	IAEA-472
I-129	45	2.6	3.8	530	MDL-MGR-MD-000001
Tc-99	20	None[(a)]	20	20	PNNL-13421
Tc-99	20	2.0	3.3	120	MDL-MGR-MD-000001

[(a)] The model element for this parameter always returns a value of 20 L/kg.

Development of probabilistic distributions for the soil-to-plant transfer factors was more complex because the reference documents provided the information for individual plant types, as described above for the deterministic calculations. Table 5 shows the distributions the DOE used to develop stochastic multipliers for the soil-to-plant transfer factors for iodine and technetium. As for the water-to-fish transfer factors, the DOE implemented the distributions so that the model selected from the distributions based on IAEA-472 in 50 percent of the realizations and selected from the distributions based on MDL-MGR-MD-000001 in the other 50 percent of the realizations. After selecting values for factors for each plant type, the DOE combined the values based on the assumed crop yields in Table 2, as it did for the deterministic values. Those calculations resulted in a theoretical range of soil-to-plant factors from 3.0×10^{-4} to 2.0 (unitless) for iodine and from 0.19 to 170 (unitless) for technetium. As discussed in Section 3.2.2. of this TRR, the DOE assumed that all locally-grown crops were contaminated and that only a portion of a member of the public's annual produce consumption would be grown locally.

Table 5. Probabilistic multipliers for transfer factors used in the 2020 SDF PA (adapted from Tables BIO-3.1 and BIO-3.2 in SRR-CWDA-2021-00047)

Plant Category	Geometric Mean	Geometric Standard Deviation	Minimum	Maximum	Reference
Iodine					
Grains	6.3×10^{-4}	2.3	1.0×10^{-4}	1.1×10^{-2}	IAEA-472
	2.5×10^{-2}	10	6.6×10^{-5}	9.4	MDL-MGR-MD-
Leafy Vegetables	6.5×10^{-3}	3.7	1.1×10^{-3}	1.0×10^{-1}	IAEA-472
	2.6×10^{-2}	9.9	7.2×10^{-5}	9.7	MDL-MGR-MD-
Fruit	1.0×10^{-1}	(a)	1.0×10^{-1}	1.0×10^{-1}	IAEA-472
	5.7×10^{-2}	2.8	4.1×10^{-3}	7.9×10^{-1}	MDL-MGR-MD-
Legumes	8.5×10^{-3}	7.4	2.0×10^{-4}	1.4×10^{-1}	IAEA-472
	(b)	(b)	(b)	(b)	MDL-MGR-MD-
Roots and Tubers	7.7×10^{-3}	3.0	1.4×10^{-3}	4.7×10^{-2}	IAEA-472
	(b)	(b)	(b)	(b)	MDL-MGR-MD-
Other	(b)	(b)	(b)	(b)	IAEA-472
	3.2×10^{-2}	4.4	7.0×10^{-4}	1.5	MDL-MGR-MD-
Technetium					
Grains	3.8	8.2	5.0×10^{-1}	5.2×10^{1}	IAEA-472
					MDL-MGR-MD-
Leafy Vegetables	1.8×10^{2}	13.5	4.5	3.4×10^{3}	IAEA-472
	4.6×10^{1}	2.6	3.8	5.5×10^{2}	MDL-MGR-MD-
Fruit	(b)	(b)	(b)	(b)	IAEA-472
	4.3	4.6	8.7×10^{-2}	2.1×10^{2}	MDL-MGR-MD-
Legumes	4.3	5.2	1.1	3.0×10^{1}	IAEA-472
	(b)	(b)	(b)	(b)	MDL-MGR-MD-
Roots and Tubers	4.6×10^{1}	3.7	1.4×10^{1}	7.9×10^{1}	IAEA-472
	(b)	(b)	(b)	(b)	MDL-MGR-MD-
Other	(b)	(b)	(b)	(b)	IAEA-472
	4.4	3.7	1.5×10^{-1}	1.2×10^{2}	MDL-MGR-MD-

(a) The underlying reference (IAEA-472) based the geometric mean for iodine uptake into fruit on a single value, so the DOE used a deterministic value for fruit and sampled from the other distributions for iodine to develop the probabilistic multiplier for soil-to-plant intake for iodine.

(b) No value was available. The DOE accounted for the missing value by scaling up the fractions for the other plant types to account for 100 percent of plant ingestion.

3.4 Crop and Soil Parameters

3.4.1 Crop Parameters

The DOE based most of the parameters related to the growth of crops on the DOE document WSRC-STI-2007-0004. The DOE used the value labeled “Deterministic Value” in Table 6 for each of the three Central Scenario Cases (i.e., the DOE did not develop separate values for the Realistic, Compliance, and Pessimistic Cases for these parameters). The deterministic

parameters the DOE used in the 2020 SDF PA are the same values the NRC staff reviewed in the 2016 TRR except for the fraction of the produce that is leafy, which changed from 0.2 (unitless) in SRR-CWDA-2013-00058, Rev. 1 to 0.222 (unitless) in Rev. 2. The probabilistic multipliers the DOE used in the 2020 SDF PA are the same as the multipliers the NRC reviewed in the 2016 Biosphere TRR except that the DOE removed the probabilistic multipliers for the crop yield and tilling depth.

Table 6. Crop parameters (adapted from Table 4.4-116 in the 2020 SDF PA)

Parameter	Unit	Deterministic Value	Probabilistic Multiplier				
			Distribution	Mean or Mode	Standard Deviation	Minimum	Maximum
Fraction of activity deposited on leaves that is retained	None	0.25	Triangular	1.0	None	0.8	1.0
Fraction of activity that remains on leaves after washing	None	1	None	None	None	None	None
Fraction of year crops are irrigated	None	0.192	Normal	1.0	0.1	0.85	1.28
Crop and garden yield	kg/m^2	2.2	None	None	None	None	None
Tilling depth	m	0.15	Triangular	1.0	None	1.0	4.1
Fraction of produce that is leafy	none	0.222	None	None	None	None	None
Garden area for family of four	m^2	100	Triangular	1.0	None	1.0	10.0

As described further in Section 3.5.1 in this TRR, the DOE calculated the local fraction of produce consumed based on assumptions about the crop yield and garden area. The DOE calculated the local fraction from the crop yield and garden area to ensure those aspects of the model were internally consistent (SRR-CWDA-2013-00058). In SRR-CWDA-2013-00058, the DOE indicated that it based the garden area for deterministic modeling in the 2020 SDF PA on the value the DOE used in the SRS H-Tank Farm and F-Tank Farm PAs. To check the consistency of the resulting local fraction of produce consumed with values in the U.S. Environmental Protection Agency (EPA) Handbook, the DOE compared the calculated local fraction with a weighted average of the mean local fractions for fruit and vegetable consumption for households who farm from the EPA Handbook. The DOE weighted the local fractions for fruit and vegetable consumption based on the ingestion of plant types in Table 2 of this TRR. The DOE indicated that the calculated weighted average of EPA Handbook values (i.e., 0.275) was similar to the local fraction of produce consumption the DOE calculated based on the deterministic values of produce yield and consumption (i.e., 0.266). The DOE indicated the similarity of the local fraction of produce consumed for households who farm in the EPA Handbook and the local fraction the DOE calculated based on the deterministic values the DOE used for garden area and crop yield suggested the DOE deterministic values for garden area and crop yield were consistent with the characteristics of the critical group.

In response to an NRC question about the assumed garden area, the DOE compared the 100 m^2 deterministic value from the Dose Model with the amount of land needed to provide produce for a family of four (SRR-CWDA-2021-00047). The DOE used an annual produce intake rate of 207 kg/year per person for deterministic calculations, as described in Section 3.5 of this TRR. For a family of four adults, the annual intake would be 828 kg/year, and multiplying that value by an assumed local fraction of 0.275 (i.e., the value described in the previous paragraph based on EPA Handbook data for households who farm) would result in an annual intake of 228 kg/year. Dividing that value by an assumed crop yield of 2.2 kg/m^2 results in a required garden area of 103 m^2.

The DOE used a deterministic sensitivity analysis to determine the effect of variation in garden size on the projected dose to a member of the public. As shown in Section 3.8 of this TRR, increasing the modeled garden area by a factor of 10 increased the projected dose to a member of the public within 10,000 years of site closure by a factor of 2.6.

The DOE based the crop yield for deterministic modeling on a weighted average crop yield for South Carolina and Georgia (SRNL-STI-2010-00447). That value (i.e., 2.2 kg/m^2) is the same value that the NRC reviewed in the 2016 Biosphere TRR.

3.4.2 Soil Parameters

The DOE used the soil properties in Table 7 and the sorption coefficients (K_d values) in Table 8 to model radionuclide buildup in soil irrigated with contaminated water. The DOE based the modeled soil properties in on a collection of DOE data compilations and analyses the DOE previously developed for the SRS (see Table 7). The DOE used the value labeled “Deterministic Value” for each of the three Central Scenario Cases (i.e., the DOE did not develop separate values for the Realistic, Compliance, and Pessimistic Cases for these parameters). The deterministic and stochastic parameters the DOE used in the 2020 SDF PA are the same values the NRC staff reviewed in the 2016 TRR except for the minimum value of the stochastic distribution for the areal density and dry bulk density of soil, which changed from 0.83 to 0.85.

To model buildup of radionuclides in surface soil due to irrigation with contaminated water, the DOE used the same sorption coefficients (i.e., K_d values) the DOE used to model radionuclide transport in sandy soil in the vadose zone and saturated zones (Table 8). Except for niobium and plutonium, the DOE took the values from the DOE document *Geochemical Data Package for Performance Assessment Calculations Related to the Savannah River Site* (SRNL-STI-2009-00473). The DOE took values for niobium and plutonium from the DOE document *Updated Sorption Constants for use in Performance Assessment Modeling* (SRR-CWDA-2017-00019). The DOE used the same deterministic values for all three cases in the Central Scenario.

In the probabilistic model, the DOE used the same stochastic distributions of sorption coefficients to model soil buildup that the DOE used for sandy soil in other parts of the model (Table 8). Each realization of the probabilistic model used one value of the sorption coefficient for each element for all instances of sandy soil in the model. For elements other than technetium, the probabilistic GoldSim model applied the selected sorption coefficient value to sandy soil in the garden (i.e., the soil buildup model, which is one part of the Dose Model for the 2020 SDF PA), the vadose zone, and the saturated zone. For technetium, the probabilistic model did not represent vadose zone transport directly because of the complexity of technetium

release from the wasteform. Instead, the DOE used the PORFLOW Vadose Zone Transport Model to generate technetium fluxes from the vadose zone for each combination of technetium solubility value, flow field, and disposal structure and the probabilistic GoldSim model selected from those fluxes. Therefore, for technetium, the probabilistic distribution in Table 8 applies to the soil buildup aspect of the Dose Model and to the abstraction of sandy soil in the saturated zone, but not to vadose zone transport.

Table 7. Soil parameters (adapted from Table 10.2-1 in SRR-CWDA-2013-00058)

Parameter	Unit	Reference	Deterministic Value	Probabilistic Multiplier				
				Distribution	Mean or Mode	Standard Deviation	Minimum	Maximum
Buildup time	yr	(a)	25	None	None	None	None	None
Areal soil density	kg/m^2	(b)	240	Normal	1.0	0.07	0.85	1.15
Dry bulk density[(d)]	kg/m^3	(c)	1,650					
Precipitation rate	m/yr	(e)	1.25	None	None	None	None	None
Evapotranspiration rate	m/yr	(e)	0.79	None	None	None	None	None
Irrigation rate	m/yr	(b)	1.32	Triangular	1.0	None	0.5	1.5
Weathering decay constant	1/yr	(b)	18.1	Triangular	1.0	None	0.6	1.0
Soil moisture content	None	(f)	0.2086	None	None	None	None	None

[(a)] SRNL-STI-2010-00477
[(b)] WSRC-STI-2007-00004
[(c)] WSRC-STI-2006-00198
[(d)] correlated to the areal soil density with a correlation factor of 1
[(e)] WSRC-STI-2007-00184
[(f)] SRR-CWDA-2010-00128

The DOE developed the stochastic distributions based on information in the DOE document SRNL-STI-2009-00473. That document based the distributions on sets of 27 measurements each for americium, cadmium, cesium, cerium, cobalt, mercury, strontium, tin, technetium, and yttrium sorption onto SRS sandy soil and generalized the results to the other elements. The probabilistic distribution parameters in Table 8 represent the uncertainty the DOE expects in the sorption coefficient for each element averaged over a large volume of soil (i.e., the volume of soil used for growing crops). That is, the standard deviation of the normal distribution in Table 8 corresponds to the standard error in the mean of the sample measurements, which each represent a small area of soil, relative to the garden area over which the 2020 SDF PA Dose Model applies the sorption coefficients.

Table 8. Sorption coefficients for modeling radionuclide buildup in soil (Adapted from Table 4.3-4 in the 2020 SDF PA)

Element	Sorption Coefficient (mL/g)	Element	Sorption Coefficient (mL/g)	Element	Sorption Coefficient (mL/g)
Actinium	1,000	Hydrogen	0	Radium	30
Aluminum	1,000	Iodine	1	Radon	0
Americium	1,000	Potassium	5	Selenium	1,000
Carbon	10	Niobium	1,000	Samarium	1,000
Californium	1,000	Nickel	7	Tin	2,000
Chlorine	1	Neptunium	3	Strontium	5
Curium	1,000	Plutonium	3	Technetium	0.6
Cobalt	40	Lead	2,000	Thorium	900
Cesium	10	Platinum	7	Uranium	300
Europium	1,000	Plutonium	650	Zirconium	900
Stochastic Distribution for Probabilistic Modeling					
Distribution	Mean	Standard Deviation		Minimum	Maximum
Normal	Deterministic Value	0.375 × mean		0.25 × mean	1.75 × mean

3.5 Intake Rates

The 2020 SDF PA used annual intake rates as part of the calculation of the internal dose contribution from inhalation and ingestion of contaminated air, water, food, and soil. Section 3.5.1 addresses annual intake rates of contaminated media for a human receptor. Section 3.5.2 addresses animal intake of contaminated soil, feed, and water, which affects a human receptor because it affects the concentrations of radionuclides in animal products.

3.5.1 Human Intake Rates

The DOE used data from the EPA Exposure Factors Handbook (EPA-600-R-090-052F) (referred to as the "EPA Handbook" in this report) to develop annual intake rates for a member of the public and chronic exposure for an inadvertent intruder. For many intake rates and activities, the EPA Handbook provides data for per capita rates, which average consumption or a time spent in activity over all individuals in the survey group, as well as "consumers-only" or "doers-only" rates, which average responses only over individuals who consume a particular substance (e.g., water, produce, fish) or engage in a particular activity. Because the DOE defined members of the critical group as engaging in certain activities, consuming contaminated water, and consuming several categories of contaminated food, the DOE used "consumers-only" or "doers-only" data when it was available in the EPA Handbook. For example, a "doers-only" value for time spent swimming would be averaged over people who swim. The alternative would be a "per capita" value, which would be averaged over all people in the nation or all people in the region being considered, including people who do not swim.

The DOE used values for adults because intake rates for an adult generally are greater than intakes for younger age groups (i.e., the DOE expected that using adult intake rates would increase the projected dose). When the EPA Handbook provided data for multiple age ranges of adults, the DOE averaged values for those age ranges. When the EPA Handbook provided information separately for males and females, the DOE averaged values based on the gender

distribution of adults in the area near SRS (i.e., 48 percent male and 52 percent female) based on county-level data for South Carolina and Georgia in *Site-Specific Reference Person Parameters and Derived Concentration Standards for the Savannah River Site* (SRNL-STI-2013-00115).

When appropriate data was available in the EPA Handbook, the DOE also considered adjustments to ensure the intake was compatible with the location and occupation of the critical group. For geographic adjustments, the DOE compared national averages to available regional averages in the EPA Handbook and used the ratio of the value for the Southern U.S. to the national average to adjust the intake rate when the adjustment resulted in increased intake. The DOE also considered adjusting for a non-metropolitan setting, when applicable, because the DOE assumed that a subsistence farmer would not live in a metropolitan setting. For occupational adjustments, the DOE considered the activity level and exposure to soil of a subsistence farmer. For example, the DOE adjusted the water intake rate based on an assumed high level of physical activity the DOE determined would be applicable for a subsistence farmer. Similarly, the DOE chose a high percentile value for incidental soil ingestion to reflect the greater exposure to soil for a farmer compared to a person with a non-agricultural occupation.

The EPA Handbook provides data on consumption of produce, meat, milk, poultry, eggs, and fish, both as mass per unit time (e.g., g/day) and as a mass consumed per unit time normalized to body weight (e.g., g/kg-day). Similarly, it provides data on the consumption of water and inhalation of air both as a volume per unit time and as a volume per unit time normalized to body weight. The EPA Handbook advises that it is inappropriate to convert values expressed as normalized to body weight to absolute masses or volumes ingested or inhaled per unit time by multiplying by an assumed body weight because the amounts consumed generally are correlated to the body weight. The DOE created the 2020 SDF PA Dose Model to use intake parameters as masses or volumes of intake per year rather than masses or volumes normalized to body weight. Therefore, for each of the intake rates addressed in this section, the DOE used data from the EPA Handbook expressed as an intake per unit time to develop intake rates for use in the model. In some cases, the DOE used data normalized to body weight to determine adjustment factors or to support the development of dimensionless probabilistic multipliers. Those instances are noted where applicable.

Table 9 shows the deterministic human intake rates the DOE used in the 2020 SDF PA in the Central Scenario Cases. Table 10 provides the probabilistic distributions the DOE used for the water, produce, meat, fish, and egg ingestion rates in probabilistic sensitivity and uncertainty analyses. The reasons the DOE did not develop probabilistic distributions for the remaining intake factors are discussed for each intake parameter individually in the remainder of this section.

Table 9. Human intake rates for the Central Scenario Cases in the 2020 SDF PA (adapted from Table 8.1-1 and text in Section 8.1 in SRR-CWDA-2012-00058)

Intake	Units	Realistic Case	Compliance Case	Pessimistic Case
Water Ingestion	L/yr (L/d)	448 (1.23 L/d)	505 (1.38 L/d)	731 (2 L/d)
Soil Ingestion	kg/yr	1.06	1.06	1.06
Produce Ingestion	kg/yr	199	207	546
Meat Ingestion	kg/yr	62.2	68.7	151
Milk Ingestion	kg/yr	67.2	75.0	201
Poultry Ingestion	kg/yr	10.4	12.1	31.2
Egg Ingestion	kg/yr	8.2	11.0	24.7
Fish Ingestion	kg/yr	17.8	17.8	31.3
Air Inhalation	m^3/yr	6,000	8,000	8,000

Table 10. Unitless probabilistic multiplier for ingestion rates in the 2020 SDF PA (adapted from Table 8.1-1 in SRR-CWDA-2012-00058)

Ingestion Rate	Distribution Type	Central Tendency		Uncertainty Measure		Minimum	Maximum
		Parameter	Value	Parameter	Value		
Water	Gamma	Mode	0.92	Standard Deviation	0.34	0.20	2.22
Produce	Log-Normal	Geometric mean	0.8	Geometric Standard Deviation	2.3	0.01	4.0
Meat	Log-Normal	Geometric mean	0.8	Geometric Standard Deviation	1.9	0.02	3.4
Fish	Triangular	Mode	17.8	Not Applicable	Not Applicable	13.8	31.3

Water Ingestion

Based on previous SDF modeling, the DOE expected water ingestion to be a significant contributor to the projected dose to a human receptor. Therefore, the NRC staff has included a detailed description of the DOE process for determining the human water intake rate in this section.

The DOE assumed the critical group would drink water from a contaminated source. The EPA Handbook recommends that site-specific exposure assessments for a hypothetical receptor who consumes contaminated water should use data for “consumption of water from community water sources.” Based on that recommendation, the DOE used the EPA Handbook consumers-only data community water sources. That choice represents a change from previous SDF PAs, which used “all-sources” water consumption data adjusted for bottled water intake. The data include both direct water ingestion (i.e., as beverage) and indirect water ingestion (i.e., used in food or beverage preparation).

The DOE used EPA Handbook tables that provided percentiles of water ingestion from two surveys: one from the 1990s and one from the 2000s. The DOE combined data from the two tables by comparing corresponding percentile values from both studies and choosing the greater of the two values for each entry. The DOE used the same process for the mean. For example, for adults 18 to 21, the DOE used the mean from the 1990s, the median from the 1990s, and the 95th percentile from the 2000s. The DOE made the same type of comparison for the 10th, 25th, 75th, 90th, and 99th percentile values.

The EPA Handbook data partitioned water ingestion rates by age into 13 groups. Of those 13 groups, the DOE determined that three represented adults: 18 to 21 years, greater than 21 years, and greater than 65 years. The EPA Handbook did not provide further information on how to interpret the overlap between the age groups for greater than 21 years and greater than 65 years (i.e., “greater than 21 years” includes “greater than 65 years”). The DOE treated the categories as separate (i.e., it treated the “greater than 21” age group as if it meant “between 21 and 65”). To combine information for the different age group for the mean and for each percentile value, the DOE calculated a weighted average for the three age groups based on the number of survey respondents in each age category. Because the number of respondents in each age category differed between the two surveys, for each age category, the DOE used the number of respondents in the survey that had the more conservative mean water ingestion rate. That is, the DOE used the number of respondents in the 18- to 21-year-old category from the 1990s study, and the number of respondents in the 2000s survey for the other two age categories.

After developing the mean and percentile values for adults, the DOE adjusted the water intake rate based on geographical region. The EPA Handbook does not provide regional data for consumption of community-sourced water. Therefore, to develop a ratio of water ingestion in the U.S. South compared to the national average value, the DOE used EPA Handbook data on daily intakes of the sum of water and juice for four regions (i.e., the Northeast, Midwest, South, and West) and the national average. Although the sum and of water and juice were not applicable to the water ingestion rate, the DOE determined that the regional differences in ingestion rate could represent the regional differences in the water ingestion rate. The DOE developed a regional adjustment factor of 1.04 for the South by taking the ratio of the mean of daily water and juice ingestion in the South compared to the mean for the nation.

To adjust water for the assumed occupation and recreational activities of the human receptor, the DOE used EPA Handbook data that related water ingestion to different activity levels. The DOE used professional judgment to choose daily activity levels using a five-step scale from the EPA Handbook: (1) not at all active, (2) not very active, (3) somewhat active, (4) very active, and (5) extremely active. The DOE assumed the human receptor was “extremely active” four days a week, “very active” two days a week, and “somewhat active” one day a week. Based on those assumptions and the associated water ingestion rates in the EPA Handbook, the DOE developed a ratio of 1.08 to adjust the water intake for the activity level of the critical group.

To develop the deterministic Compliance Case value for the water ingestion rate, the DOE multiplied the mean rate the DOE developed by combining survey rates and age groups (i.e., 448 L/yr) by the activity adjustment factor (i.e., 1.08) and the regional adjustment factor (i.e., 1.04), resulting in an ingestion rate of 505 L/year. For the Realistic Case, the DOE used the same mean ingestion rate without adjustments for the geographic region or occupation of the human receptor (i.e., 448 L/yr). For the Pessimistic Case, the DOE did not base the ingestion rate on the data from the EPA Handbook, and instead used a benchmark value of 2 L/day (i.e., 731 L/yr), which the EPA has used in screening analyses.

For the probabilistic distribution, the DOE scaled the percentiles from the survey data to reflect annual ingestion rates because the survey data were based on 2-day consumption periods. The DOE determined scaling was necessary because the DOE expected that variation in water consumption rates within a 2-day period was likely to be greater than variation over a year (i.e., the period relevant to the dose projection). To scale the variation from the 2-day survey period, the DOE used the percentiles the DOE developed from combining the data from the 1990s survey and the 2000s survey as input to a GoldSim model that selected a drinking water intake for a hypothetical individual for every 2-day period for one year.

To account for individual habits that would tend to keep water intakes similar from day to day, the DOE correlated each selection with the previous selection in a process called "auto-correlation." A correlation factor of zero would imply that the water ingestion rate in each 2-day period was random, whereas a correlation factor of one would imply that an individual consumed the same amount of water in each 2-day period. To develop an appropriate correlation factor, the DOE used professional judgment to establish an upper bound for the annual intake and then selected the correlation factor that yielded a maximum intake rate closest to that maximum value when the model was run for 5,000 realizations. Specifically, the DOE determined that an individual was unlikely to maintain or exceed the 95th percentile of water ingestion from any 2-day period for an entire year. Therefore, the DOE used the 2-day 95th percentile water ingestion rate (3,056 mL/d) to establish an upper bound for the annual ingestion rate (1,116 L/yr). After testing sets of 5,000 realizations with different correlation coefficients, the DOE determined that a correlation coefficient of 0.95 yielded a maximum value slightly lower than 1,116 L/yr and a correlation coefficient of 0.96 yielded a maximum slightly greater than 1,116 L/year.

The DOE then used the GoldSim model with a correlation coefficient of 0.96 to develop an empirical distribution for the annual water ingestion rate. To develop a theoretical distribution for the annual water intake rate, the DOE fit distributions to the GoldSim output between the 5th and 95th percentile of realizations. Specifically, the DOE used R-squared values and root mean squared error values to compare the optimized fit of six different theoretical distributions to the empirical distribution: normal, log-normal, gamma, beta, uniform, and triangular. The DOE determined that a gamma distribution provided the best fit. The DOE did not apply the geographic or occupational adjustment factors to the probabilistic distribution.

Soil Ingestion

To select an intake rate for incidental soil ingestion, the DOE evaluated data from the EPA Handbook to determine which data set best represented the characteristics of the critical group. Most of the data in EPA Handbook related to soil ingestion was from studies of soil ingestion in children. Because the critical group for the 2020 SDF PA is defined as an adult, only two studies in the EPA Handbook applied. Of those two studies, the EPA Handbook indicated that one provided data for deliberate, rather than incidental, soil ingestion. The other study provided estimated ranges for the mean, median, and 95th percentile values for incidental soil ingestion. The value the DOE selected (1.06 kg/yr) corresponded to the maximum of the range for the 95th percentile. The DOE used that value for all three Central Scenario Cases. In SRR-CWDA-2013-00058, the DOE indicated that it did not develop a probabilistic distribution for incidental soil ingestion because the deterministic value chosen was from an upper percentile and there is limited data available to support a distribution of soil ingestion rates.

Produce Ingestion
Based on previous SDF modeling, the DOE expected plant ingestion to be a significant contributor to the projected dose to a human receptor near the SDF. Therefore, the NRC staff has included a detailed description of the DOE process for determining the produce intake rate in this section.

To develop deterministic values for the Central Scenario Cases, the DOE evaluated EPA Handbook data for consumer-only mean daily produce intake rates. The EPA Handbook data were based on dietary surveys conducted in 1977-1978, 1987-1988, 1994, and 1995. The DOE performed several calculations before determining which of the four surveys to use. For the survey from 1977-1978, the DOE averaged the results from six age groups in the adult age range by giving each age group equal weight. For the other three surveys, the survey included an age group of greater than or equal to 20 years, which the DOE used directly. Then the DOE performed three steps for each survey: (1) gender-weighted values based on the gender ratio in the vicinity of SRS (i.e., 48 percent male and 52 percent female), (2) summed values for fruits and vegetables, and (3) converted the daily average intake rate in g/day to kg/year by multiplying by 365.25 d/year and 1 kg/1000 g. After performing those steps, the DOE chose to use the 1994 data because it resulted in the greatest average produce intake rate from the four studies.

The DOE used EPA Handbook data to determine that adjustments for the geographical region (i.e., the South) or for rural areas would decrease the assumed produce ingestion rate in comparison to the national average. Therefore, the DOE chose not to apply any adjustment factors. For the Compliance Case, the DOE used the intake rate based on the average intake rate in the 1994 survey, after applying the calculations indicated in the previous paragraph. For the Realistic Case, the DOE averaged the values from the four studies (i.e., 1977-1978, 1987-1988, 1994, and 1995) after applying the calculations above. For the Pessimistic Case, the DOE applied the 95^{th} percentile multiplier from the probabilistic distribution described below to the Compliance Case value.

The survey data the DOE used to develop deterministic produce ingestion rates did not include percentile data. Therefore, to develop a stochastic distribution for the produce ingestion rate, the DOE used EPA Handbook consumers-only data for produce ingestion normalized to body mass, which included percentile values. Although the data normalized to body mass were not directly applicable to the ingestion rate parameter used in the DOE model, the DOE determined that the variation in the normalized ingestion rate could represent the variability in the ingestion rate. The percentile values were based on survey data from 1994 through 1996 and 1998. The survey included two age categories in the adult age range: 20 to 49 years and greater than or equal to 50 years. To develop a value for adults, the DOE calculated weighted averages for each percentile value based on the number of survey respondents in each category. Then, for each percentile, the DOE added the fruit ingestion rate to the vegetable ingestion rate. To develop a multiplier, the DOE divided each percentile by the mean intake rate.

After developing the percentile values, the DOE fit five different distribution shapes to the percentile values from the 10^{th} to the 90^{th} percentile: normal, log-normal, gamma, uniform, and triangular. The DOE determined that a log-normal distribution provided the best fit to the data based on the R-squared value and the root mean square value. The DOE used the 1^{st} percentile value as a minimum value for the distribution and the 99^{th} percentile value as a maximum.

Meat Ingestion
To develop a deterministic meat ingestion rate, the DOE used data from four surveys in the EPA Handbook (Tables 11-7 through 11-9 in the EPA Handbook). Because the surveys included poultry in "total meat" and the DOE accounted for poultry separately, the DOE first added all of the non-poultry categories of meat (i.e., beef, pork, lamb, veal, game, frankfurters, sausages, lunch meats, spreads, and meat mixtures) separately for males and females for each age group. Then, for each survey, the DOE took a gender-weighted average of meat ingestion for each adult age group to yield a summary value for that survey.

The DOE did not apply a regional adjustment factor to meat consumption because regional data showed that meat consumption in the South is equal to the national average (Table 11-18 in the EPA Handbook). The same table in the EPA Handbook showed a slightly higher mean meat ingestion rate for individuals outside of metropolitan areas. Therefore, based on DOE developed an adjustment factor of 1.05 for the rural setting based on the ratio of the mean meat ingestion rate outside of a metropolitan area to the national average.

For the Compliance Case, the DOE chose the maximum value from the four summary values adjusted for a rural setting. For the Realistic Case, the DOE chose the average of the four survey summary values without any adjustment. For the Pessimistic Case, the DOE used the 95^{th} percentile of the probabilistic distribution the DOE developed for the meat ingestion rate, as discussed further below.

In the EPA Handbook, percentiles of meat ingestion rates were available for meat ingestion rates normalized to body weight (i.e., g/kg-day). Although those values were not directly comparable to the ingestion rate expressed as g/day, the DOE determined the variation in the normalized values could be used to develop a stochastic multiplier for use in probabilistic modeling. To develop a multiplier, the DOE first averaged the data for two adult age groups (i.e., 20 to 49 years and greater than 50 years) for each percentile value and then divided the percentile values by the mean. To develop a distribution, the DOE fit normal, log-normal, gamma, uniform, and triangular distributions to the data between the 10^{th} and 90^{th} percentile. The DOE found that a log-normal distribution produced the best fit based on the R-squared value and the root mean square error.

Milk and Eggs
To develop deterministic ingestion rates for milk and eggs, the DOE used data from four surveys in the EPA Handbook (Tables 11-10 through 11-12 in the EPA Handbook). For both milk and eggs, the DOE first took a gender-weighted average of the ingestion rate for each age group of individuals greater than 18 years old to yield a summary value for that survey. For the Compliance Case, the DOE chose the maximum value from the four summary values. For the Realistic Case, the DOE chose the average of the four values. For the Pessimistic Case, the DOE chose a value three times greater than the realistic value.

The data the DOE used was based on per capita milk or egg consumption rather than consumers-only consumption. However, the DOE expected the difference would be insignificant based on data in the EPA Handbook that included both per capita and consumers-only consumption normalized to body weight (i.e., comparison of Tables 11-17 and 11-18 in the EPA Handbook). The DOE did not adjust the ingestion rate for either milk or eggs for the region (i.e., the South) or for a rural setting because data from the EPA Handbook showed that both adjustments would lower the ingestion rates.

The DOE did not develop a probabilistic distribution for annual intake of milk or eggs because the DOE did not expect milk or egg ingestion to make a significant contribution to the projected dose to a human receptor in the 2020 SDF PA.

Poultry Ingestion
To develop deterministic ingestion rates for poultry, the DOE used data from four surveys reported in the EPA Handbook (see Tables 11-7 through 11-9 in the EPA Handbook). For each survey, the DOE took a gender-weighted average of poultry ingestion for each age group of individuals greater than 18 years old to yield a summary value for that survey. The data the DOE used was based on per capita poultry consumption rather than consumers-only poultry consumption. However, the DOE expected the difference would be insignificant based on data in the EPA Handbook that showed very similar values for per capita and consumers-only total meat ingestion rates normalize to body weight (Table 11-1 in the EPA Handbook).

The EPA Handbook did not include data for poultry consumption that would support adjustments for regional differences or a rural setting. Therefore, the DOE used the same adjustment factors for poultry that it did for other terrestrial meat. That is, the DOE made no adjustment for the region (i.e., the South) and used an adjustment factor of 1.05 based on the assumed rural setting. For the Compliance Case, the DOE chose the maximum value from the four summary values, adjusted for the rural setting. For the Realistic Case, the DOE chose the average of the four values without any adjustment. For the Pessimistic Case, the DOE chose a value three times greater than the realistic value.

The DOE did not develop a probabilistic distribution for annual poultry ingestion because poultry ingestion did not make a significant contribution to the projected dose in the 2020 SDF PA.

Fish Ingestion
For the fish ingestion rate, the DOE used data from the EPA Handbook based on interviews with people fishing along the Savannah River. For deterministic modeling, the DOE used the mean ingestion rate from all the survey respondents for both the Realistic and Compliance Cases. The DOE used the mean value for the sub-group with the greatest ingestion rate (i.e., people who did not graduate from high school) as the maximum value. Because the values were based on site-specific information, the DOE did not apply any adjustment factors based on location.

For a probabilistic distribution, the DOE used a triangular distribution with a mode equal to the average ingestion rate from all the survey respondents (i.e., the same value used in deterministic modeling for the Realistic and Compliance Cases). For the minimum, the DOE used the mean for the sub-group with the lowest ingestion rate (i.e., high school graduates). For the maximum, the DOE used the mean ingestion rate for the sub-group with the greatest ingestion rate (i.e., the same value used for the Pessimistic Case in deterministic modeling).

Air Inhalation
The DOE based the deterministic values of the inhalation rate (i.e., volume of air inhaled per year) for the Central Scenario Cases on recommended daily values from the EPA Handbook, multiplied by 365.25 days/yr to convert to annual values. For the Compliance Case, the DOE averaged the recommended 95th percentile values for five age groups, which the DOE weighted equally: 16 to 21 years, 21 to 31 years, 31 to 41 years, 41 to 51 years, and 51 to 61 years. The DOE selected those age groups based on the assumption that the human receptor would

perform farm work from an age of 16 to 61. The DOE then rounded the result to one significant digit. For the Realistic Case, the DOE used the recommended mean values and used the same averaging and rounding steps described above. The DOE chose not to use different values for the Pessimistic Case because the DOE found the Compliance Case value to be conservative.

The DOE chose not to develop a stochastic distribution for the inhalation rate. Although the DOE did not provide a reason, the choice not to develop a stochastic multiplier for the air intake rate is consistent with the DOE decisions not to develop stochastic distributions for other intake factors related to pathways that do not make a significant contribution to the projected dose to a human receptor.

Local Fractions
For each substance a human receptor would ingest (e.g., water, produce, milk), the DOE assumed a certain fraction would be obtained locally and could therefore be contaminated. Table 11 provides the parameters for triangular distributions for the local fractions of water, plants, and animal products the DOE used in the 2020 SDF PA. For deterministic modeling, the DOE used the mode of each distribution in Table 11 for the Realistic Case, Compliance Case, and Pessimistic Case.

Table 11. Local fractions (adapted from Table 10.3-1 of SRR-CWDA-2013-00058)

Parameter	Mode (and Deterministic Value) (unitless)	Minimum (unitless)	Maximum (unitless)
Water	1.0	1.0	1.0
Produce	Equation 1, below	Not applicable	Not applicable
Meat	0.319	0.160	0.638
Milk	0.254	0.127	0.508
Poultry	0.319	0.160	0.638
Eggs	0.254	0.127	0.508
Fish	0.325	0.163	0.650

The DOE based the modes of the distributions in Table 11 on data for homegrown foods in the EPA Handbook. For all local fractions other than the local fraction of water, fish and produce, the DOE used values for “households who farm.” For water, the DOE used a value of 1.0 for all deterministic and probabilistic values because the fraction of water taken from a contaminated source is accounted for in the EPA Handbook’s recommended values for the use of water from a community water source. For fish, the DOE used values for “households who fish.” The DOE used a factor of two greater than the mode for the maximum value and half the mode for the minimum value.

For the local fraction for produce, the DOE used Equation 1, below, to ensure that the local fraction was consistent with model assumptions about garden area and crop yield. The DOE assumed the garden supported four people.

$$\text{Local Fraction of Produce} = \frac{Garden\ Yield \times Garden\ Area}{annual\ plant\ intake\ per\ person} \times \frac{1}{4\ people \times 1\ year} \qquad \text{Eqn. 1}$$

For the deterministic values the DOE chose for the garden yield, garden area, and plant intake rate, Equation 1 results in a value of 0.266 (unitless).

3.5.2 Animal Intake Factors

Animal intake of water and feed affects the projected dose to human receptor by transporting radionuclides through the food chain. The DOE based the animal intake factors on two reference documents: (1) the DOE document, *Baseline Parameter Update for Human Health Input and Transfer Factors for Radiological Performance Assessments at the Savannah River Site* (WSRC-STI-2007-00004) and (2) the NRC Contractor document, *Description of Methodology for Biosphere Dose* (ADAMS Accession No. ML083190829). The DOE assumed that the entire amount of each medium (i.e., water, fodder, soil) taken in by the animals would be contaminated (i.e., local fraction = 1).

The DOE used the animal intake factors in Table 12 for each of the Central Scenario Cases in the 2020 SDF PA. The values in Table 12 are the same as the deterministic values the NRC staff reviewed in the 2016 Biosphere TRR. The only difference in the implementation of animal uptake factors between the version the NRC staff reviewed in the 2016 Biosphere TRR and the version in the 2020 SDF PA is that the DOE did not use stochastic multipliers for any of the animal intake factors in the 2020 SDF PA and it previously had used stochastic distributions for the consumption of water and fodder by terrestrial livestock and milk cows.

Table 12. Animal intake factors (Adapted from Table 8.2-1 in SRR-CWDA-2013-00058)

Ingestion	Unit	Value
Water by terrestrial livestock (meat)	L/yr	10,200
Fodder by terrestrial livestock (meat)	kg/yr	13,100
Water by milk cows	L/yr	18,300
Fodder by milk cows	kg/yr	19,000
Water by poultry	L/yr	110
Fodder by poultry	kg/yr	36.5
Soil by poultry	kg/yr	3.65
Water by egg producers	L/yr	110
Fodder by egg producers	kg/yr	36.5
Soil by egg producers	kg/yr	3.65

3.6 External Exposure and Inhalation Parameters

Table 13 provides exposure and inhalation parameters that the DOE used in the 2020 SDF PA. The DOE used the value labeled “Deterministic Value” for each of the three Central Scenario Cases. The DOE did not develop stochastic distributions for these parameters.

Time Fractions

The DOE based the time fractions in Table 13 on data from the EPA Handbook, except for time spent boating and fishing. For boating and fishing, the DOE based time fractions on a DOE data compilation, as explained further below. For all other activities, the DOE used EPA Handbook data for “doers only.” The DOE divided the minutes per day, week, or month provided in the EPA Handbook by the number of minutes in the appropriate time period to yield the time fractions in Table 13. As in the model the NRC staff reviewed in the 2016 Biosphere TRR, the DOE did not include external dose from time spent indoors as an exposure pathway, except for external dose from contaminated water while showering or bathing. The DOE included the inhalation dose from the activities listed in Table 13, some of which might occur indoors (e.g., showering). The DOE also did not include the inhalation dose from other indoor time (e.g., sleeping) in the Dose Model. Therefore, there is no category labeled “indoor time” in Table 13.

Table 13. Exposure and inhalation parameters (Adapted from Table 10.1-1 in SRR-CWDA-2013-00058)

Parameter	Unit	Deterministic Value	Reference
Fraction of time in garden or crop	None	0.217	a
Fraction of time in shower or bath	None	0.012	a
Geometry factor for showering or bathing	None	1	b
Fraction of time swimming	None	0.0041	a
Geometry factor for swimming	None	1	b
Fraction of time boating or fishing	None	0.0073	c
Geometry factor for boating and fishing	None	0.5	b
Airborne release fraction	None	1.0×10^{-4}	d
Moisture content of ambient air	kg/m^3	0.001	b
Moisture content of shower air	kg/m^3	0.041	e
Mass loading of soil in the air	kg/m^3	1.0×10^{-7}	f

[a] EPA Handbook
[b] SRR-CWDA-2013-00058
[c] SRNL-STI-2015-00056
[d] DOE-HDBK-3010-94
[d] HNF-SD-WM-TI-707
[e] UCRL-76419

The DOE calculated the dose from inhalation of volatilized radionuclides for a member of the public 100 m from the SDF in a separate GoldSim model, which the DOE referred to as the Air Pathway Release Model. That model projected the inhalation dose from carbon-14, chlorine-36, tritium, iodine-129, selenium-79, antimony-125, antimony-126, tin-126, and technetium-99. It also calculated the radon flux at the SDF surface from radon based on its ingrowth from seven parent radionuclides: curium-246, plutonium-242, plutonium-238, uranium-238, uranium-234, thorium-230, and radium-226. The DOE used the Air Pathway Release Model to project radionuclide fluxes at the ground surface above the SDF, and then used the EPA software CAP-88 to calculate dose release factors at the 100 m boundary. The model assumed radionuclides moved in the air phase up from saltstone through the engineered barriers above the disposal units up to the erosion barrier, where the model simulated their release to the atmosphere (i.e., the model did not include layers above the erosion barrier). The DOE Air Release Pathway Model projected that the dose to a member of the public at the 100 m boundary would be less than 1×10^{-6} mSv/yr ($< 1 \times 10^{-8}$ mrem/yr). The Air Pathway Release Model also projected that the radon flux at the surface of the SDF above each disposal structure would be almost five orders of magnitude below the 0.74 Bq per m^2/s (20 pCi per m^2/s) DOE limit within 10,000 years of site closure.

The largest time fraction for the human receptor was the time spent in a garden or crop. For that value, the DOE began with an upper percentile of the distribution for the time spent outdoors based on the assumption that an individual who engages in subsistence farming would spend a relatively large amount of time outdoors. The DOE then subtracted out time spent in other activities and assumed the rest of the time was spent working with crops or in a garden.

The DOE used the 95th percentile value of time spent outdoors (i.e., 495 minutes per day [min/day], equal to a time fraction of 0.344). For time spent in outdoor activities, the EPA Handbook provided national averages for different age groups and values that combined all age

groups in different geographical areas. The DOE selected data for the South for combined age groups.

Because the definition of the critical group specified that the human receptor would spend time in water recreation activities, the DOE used EPA Handbook data for the mean time spent "Outdoors at a Pool/River/Lake" (i.e., 182.2 min/day, equal to a time fraction of 0.127) and subtracted that time from the total time spent outdoors, resulting in a time fraction of 0.217 (i.e., 313 min/day) spent in a garden or crop.

For time spent swimming, the DOE used the DOE used data for time spent in freshwater pools. The EPA Handbook provided percentile values for time spent in pools without providing a mean. Without a mean, the DOE chose to use an upper percentile value for conservatism. Specifically, the DOE used the recommended 95th percentile value for swimming in the EPA Handbook. The DOE noted that EPA Handbook indicated that the 95th percentile value (i.e., 181 min/month) was the maximum value recommended for modeling, although some survey respondents reported greater time spent swimming. That value resulted in a time fraction of 0.0041 (i.e., 181 min/month divided by a total of 43800 min in a month).

For boating and fishing, the DOE used values from the DOE document *Dose Calculation Methodology and Data for Solid Waste Performance Assessment and Composite Analysis at the Savannah River Site* (SRNL-STI-2015-00056). That document complied data from other DOE documents. For time spent boating and fishing, it listed a hierarchy of other DOE documents from which the values were developed. The time fraction for boating for the "reference person" in SRNL-STI-2015-00056 was 0.00502 (i.e., 44 hr/yr). The reference did not list a value for fishing; however, it did list a value for the "fraction of year on river (stream) shore" for the reference person of 0.00228 (i.e., 20 hr/yr). The sum of those two fractions (i.e., 0.00502 and 0.00228) corresponds to the fraction 0.0073 the DOE used for the time spent boating or fishing in the 2020 SDF PA.

As a check, the DOE compared the sum of the time fractions for swimming, boating, and fishing to the EPA Handbook data for time spent at a pool, river, or lake (i.e., a mean of 182.2 min/day, equal to a time fraction of 0.127). The DOE noted that the sum of the time fractions for swimming, boating, and fishing accounted for a time fraction of 0.0114 (i.e., 16.5 min/day). The DOE assumed that the human receptor would spend the remaining time (i.e., a fraction of 0.122, or 166 min/day) at a distance from the water that would make the external dose insignificant.

For time spent showering or bathing, the EPA Handbook provided national averages of data grouped by age, without regional data. To represent an adult, the DOE averaged the mean time spent showering or bathing for two age groups: 18 to 65 and 65 or greater. The result was 17 min/day, corresponding to a time fraction of 0.012.

Geometry Factors

The geometry factors in Table 13 represent the fraction of a person the DOE assumed to be exposed to direct radiation during an activity. For swimming, showering, and bathing, the DOE chose to use the upper bound value of 1.0. For boating and fishing, the DOE chose a value of 0.5, which the DOE identified as a conservative choice based on professional judgment.

ARF and Soil Mass Loading
The DOE used an ARF of 1×10^{-4} (unitless) to model water in the air during irrigation of crops, swimming, showering, and bathing. The DOE based the value on information in the DOE document *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities, Volume 1 – Analysis of Experimental Data* (DOE-HDBK-3010-94) for aqueous liquids in free fall. The DOE chose a value between the median of 4×10^{-5} (unitless) and 2×10^{-4} (unitless), which the document HDBK-3010-94 reported as a bounding value.

The DOE used a soil mass loading of 1.0×10^{-7} kg/m^3 to model the loading of soil in the air while in a garden or crop. To support that value, the DOE cited the DOE document *Resuspension and redistribution of Plutonium in Soils* (UCRL-76419). That reference indicates the value is partly based on a 1966 study of particle concentrations in air at 30 "nonurban" sites, which ranged from 9×10^{-9} kg/m^3 to 7.9×10^{-8} kg/m^3.

Moisture Contents
The DOE developed two moisture contents of air for the 2020 SDF PA: one for time spent showering or bathing, and one for time spent in a garden or swimming. For time spent showering, the DOE used a value of 0.041 kg/m^3. To support that value, the DOE referenced the DOE document *Exposure Scenarios and Unit Dose Factors for Hanford Tank Waste Performance Assessments* (HNF-SD-WM-TI-707). That document based the moisture content of air in a shower the evaporation of water droplets at temperatures and pressures characteristic of a shower. For ambient air, the DOE characterized the value of 0.01 kg/m^3 for ambient air as a conservative assumption.

3.7 DCFs

In the 2020 SDF PA, the DOE used DCFs to convert projected external exposures or intakes of radionuclides by ingestion or inhalation to a total effective dose equivalent. The DOE used two sources for DCFs for the 2020 SDF PA. For external exposure to soil or water, the DOE used DCFs from Federal Guidance Report (FGR) 15. For external exposure to soil, the DOE used DCFs based on a 15-cm contamination depth. The DOE did not take credit for additional distance or shielding that could occur while operating farm equipment. For external exposure to water, the DOE used DCFs for water submersion, adjusted by a geometry factor to account for the fraction of the body submerged. For ingestion and inhalation intakes, the DOE used DCFs from the DOE technical standard "Derived Concentration Technical Standard" (DOE-STD-1196-2011). That DOE technical standard indicates that the DOE calculated the DCFs for internal exposure "in the manner of [International Commission on Radiation Protection (ICRP)] Publication 72" with updated physiological parameters from ICRP Publication 89 and updated decay data from ICRP Publication 107.

Although the DOE cited the same document (i.e., DOE-STD-1196-2011) as the source of the ingestion and inhalation DCFs in both Rev. 1 and Rev. 2 of SRR-CWDA-2013-00058, almost all the internal DCFs changed between those two revisions. There are two reasons for those changes. First, the DOE changed which human receptor it used between Rev. 1 and Rev. 2 of SRR-CWDA-2013-00058. In Rev. 1, the DOE used DCFs for the "Reference Person" in DOE-STD-1196-2011, which represented an age-weighted average for a representative population from the United States. For the 2020 SDF PA, the DOE switched to using the "Adult" DCF values from DOE-STD-1196-2011. That change in the human receptor from the reference person to the adult lowered the DCF for most radionuclides because, in general, the adult

human receptor has a lower DCF than younger age groups, which are part of the weighted average for the reference person. For inhalation, the DCFs for both Tc-99 and I-129 decreased by 10 percent compared to the values the NRC reviewed in the 2016 TRR. For ingestion, the DCF for I-129 decreased by 11 percent and the DCF for Tc-99 decreased by 29 percent.

For the inhalation DCFs, the DOE also changed the assumed lung absorption class for several radionuclides. In the 2016 Biosphere TRR, the NRC staff noted that in Rev. 1 of SRR-CWDA-2013-00058, the DOE had assumed fast (i.e., “F” class) absorption for all radionuclides without demonstrating that the choice was either technically justified or conservative for each radionuclide. In Rev. 2 of SRR-CWDA-2013-00058, the DOE selected the lung absorption class so that it was either the value the DOE recommended in DOE-STD-1196-2011 or the most conservative (i.e., greatest) value for that radionuclide. For several radionuclides, changing the absorption class changed the inhalation DCF by one or two orders of magnitude. For Tc-99 and I-129, the assumed absorption classes did not change, and the only change from the 2016 TRR values resulted from the change in the assumed human receptor.

Table 14 shows the DCF values the DOE used in the 2020 SDF PA. For the following seventeen decay chains, the DOE added the product of each progeny’s DCF and branching factor to the DCF for the parent:

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

Table 14. Dose conversion factors (adapted from Table 4.4-108 of the 2020 SDF PA)

Nuclide	Internal		External	
	Ingestion†	Inhalation‡	Soil Exposure‡	Water Immersion‡
	(mrem/pCi)		(m^3×mrem)/(pCi×yr)	
Ac-227*	1.61×10^{-3}	6.42×10^{-1}	1.21×10^{-6}	4.32×10^{-6}
Al-26	1.29×10^{-5}	4.03×10^{-4}	8.59×10^{-6}	3.16×10^{-5}
Am-241	7.55×10^{-4}	1.54×10^{-1}	2.56×10^{-8}	1.42×10^{-7}
Am-242m*	7.34×10^{-4}	1.49×10^{-1}	2.95×10^{-8}	1.30×10^{-7}
Am-243*	7.54×10^{-4}	1.52×10^{-1}	5.33×10^{-7}	2.03×10^{-6}
C-14	2.15×10^{-6}	7.51×10^{-6}	0.0	3.30×10^{-10}
Cf-249	1.30×10^{-3}	6.22×10^{-1}	9.75×10^{-7}	3.32×10^{-6}
Cf-251	1.32×10^{-3}	6.33×10^{-1}	2.88×10^{-7}	1.06×10^{-6}
Cl-36	3.43×10^{-6}	1.40×10^{-4}	1.48×10^{-9}	2.21×10^{-8}
Cm-243	5.55×10^{-4}	1.17×10^{-1}	3.27×10^{-7}	1.18×10^{-6}
Cm-244	4.55×10^{-4}	9.84×10^{-2}	9.25×10^{-11}	9.53×10^{-10}
Cm-245	7.70×10^{-4}	1.57×10^{-1}	2.25×10^{-7}	8.75×10^{-7}
Cm-247*	7.07×10^{-4}	1.43×10^{-1}	9.97×10^{-7}	3.44×10^{-6}
Co-60	1.27×10^{-5}	3.77×10^{-5}	8.08×10^{-6}	2.97×10^{-5}
Cs-135	9.81×10^{-6}	3.39×10^{-6}	0.0	2.72×10^{-9}
Cs-137*	5.03×10^{-5}	1.73×10^{-5}	1.67×10^{-6}	5.81×10^{-6}
Eu-152	4.96×10^{-6}	3.45×10^{-4}	3.63×10^{-6}	1.32×10^{-5}
Eu-154	7.29×10^{-6}	3.96×10^{-4}	3.92×10^{-6}	1.42×10^{-5}
H-3	1.55×10^{-7}	1.67×10^{-7}	0.0	0.0
I-129	4.00×10^{-4}	1.36×10^{-4}	5.55×10^{-9}	6.14×10^{-8}
K-40	2.28×10^{-5}	3.13×10^{-4}	5.16×10^{-7}	1.94×10^{-6}
Nb-93m	4.77×10^{-7}	1.98×10^{-6}	1.76×10^{-11}	7.33×10^{-10}
Nb-94	6.40×10^{-6}	3.96×10^{-5}	4.94×10^{-6}	1.75×10^{-5}
Ni-63	5.74×10^{-7}	1.80×10^{-6}	0.0	0.0
Np-237*	3.99×10^{-4}	8.40×10^{-2}	6.46×10^{-7}	2.29×10^{-6}
Pa-231	1.77×10^{-3}	8.51×10^{-1}	9.46×10^{-8}	3.30×10^{-7}
Pb-210*	7.06×10^{-3}	1.67×10^{-2}	4.90×10^{-9}	4.43×10^{-8}
Pt-193	1.32×10^{-7}	2.48×10^{-6}	3.19×10^{-13}	1.00×10^{-10}
Pu-238	8.44×10^{-4}	1.71×10^{-1}	4.88×10^{-11}	8.03×10^{-10}
Pu-239	9.29×10^{-4}	1.86×10^{-1}	1.60×10^{-10}	8.68×10^{-10}
Pu-240	9.29×10^{-4}	1.86×10^{-1}	5.11×10^{-11}	7.86×10^{-10}
Pu-241	1.75×10^{-5}	3.33×10^{-3}	3.37×10^{-12}	1.34×10^{-11}
Pu-242	8.84×10^{-4}	1.76×10^{-1}	2.83×10^{-10}	1.56×10^{-9}
Pu-244*	8.85×10^{-4}	1.73×10^{-1}	1.08×10^{-6}	3.85×10^{-6}
Ra-226*	1.04×10^{-3}	1.29×10^{-2}	5.52×10^{-6}	2.02×10^{-5}
Ra-228*	3.11×10^{-3}	1.68×10^{-1}	4.87×10^{-6}	1.79×10^{-5}
Se-79	1.01×10^{-5}	4.00×10^{-6}	0.0	3.86×10^{-10}
Sm-151	3.66×10^{-7}	3.43×10^{-5}	2.81×10^{-13}	5.73×10^{-12}
Sn-126*	1.81×10^{-5}	5.89×10^{-4}	5.11×10^{-6}	1.78×10^{-5}
Sr-90*	1.12×10^{-4}	1.37×10^{-4}	2.47×10^{-8}	1.24×10^{-7}
Tc-99	2.38×10^{-6}	1.49×10^{-5}	1.14×10^{-12}	3.62×10^{-9}
Th-229*	2.36×10^{-3}	3.18×10^{-1}	7.00×10^{-7}	2.57×10^{-6}
Th-230	7.92×10^{-4}	5.18×10^{-2}	7.16×10^{-10}	3.35×10^{-9}
Th-232	8.55×10^{-4}	9.18×10^{-2}	3.14×10^{-10}	1.74×10^{-9}

Table 14 (continued). Dose conversion factors (adapted from Table 4.4-108 of the 2020 SDF PA)

Nuclide	Internal		External	
	Ingestion†	Inhalation‡	Soil Exposure‡	Water Immersion‡
	(mrem/pCi)		(m^3×mrem)/(pCi×yr)	
U-232*	1.76×10^{-3}	1.88×10^{-1}	2.15×10^{-6}	8.10×10^{-6}
U-233	1.89×10^{-4}	1.31×10^{-2}	5.56×10^{-10}	2.37×10^{-9}
U-234	1.83×10^{-4}	1.29×10^{-2}	2.07×10^{-10}	1.39×10^{-9}
U-235*	1.74×10^{-4}	1.14×10^{-2}	4.55×10^{-7}	1.63×10^{-6}
U-236	1.72×10^{-4}	1.18×10^{-2}	9.85×10^{-11}	8.82×10^{-10}
U-238*	1.78×10^{-4}	1.06×10^{-2}	8.53×10^{-8}	3.47×10^{-7}
Zr-93	3.96×10^{-6}	3.63×10^{-5}	0.0	7.85×10^{-14}

* DCFs reflect the sum of the DCF for the parent radionuclide and the DCFs of each short-lived progeny multiplied by its branching factor.

† Values for ingestion and inhalation dose coefficients for the “Adult” human receptor from Tables 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 are from FGR 15.

3.8 Sensitivity Analyses

3.8.1 Probabilistic Analyses

The DOE used the stochastic distributions in Sections 3.3 through 3.5 in probabilistic sensitivity and uncertainty analyses to support the 2020 SDF PA. Except for the distributions related to transfer factors in Tables 4 and 5, the DOE included the distributions in the probabilistic analysis in the 2020 SDF PA. Subsequently, the DOE revised the analysis by including stochastic distributions related to the soil-to-plant and water-to-fish transfer factors for I-129 and Tc-99 in Tables 4 and 5 (SRR-CWDA-2021-00047).

The DOE used the Partially Ranked Correlation Coefficient (PRCC) and the Standardized Ranked Regression Coefficient (SRRC) to identify parameters that have the greatest effect on the projected dose. In general, the PRCC shows how much a stochastic parameter and the model output tend to increase or decrease together, after adjusting for the effects of other variables. Because the relationship between parameter values and the model output can change as the simulation progresses, the DOE presented the PRCCs as functions of time after closure. In contrast, the SRRC uses linear regression to evaluate how much the realization-to-realization variation in the model output at a specified time can be attributed to the variation in each stochastic parameter. The DOE calculated the SRRC at 1,000 years and 10,000 years after closure.

In the 2020 SDF PA, the DOE calculated PRCC and safety-related control circuit (SRCC) values based on the projected dose from the sector with the highest does at each timepoint (i.e., the dose from “any sector”) and the two sectors with the highest projected peak doses (i.e., Sector B and Sector D). Specifically, the DOE used the following model results for the probabilistic sensitivity analysis for a member of the public:

- total dose in any sector
- total dose in Sector B
- total dose in Sector D
- I-129 dose in any sector
- Tc-99 dose in any sector

For the revised analysis, the DOE evaluated the PRCC and SRCC based on the projected total dose in any sector. Both the PRCC and SRRC use rank-transformed data rather than the actual input and output values, which tends to reduce the effects of extreme values on the sensitivity analysis.

Table 15 summarizes the biosphere parameters that the DOE identified as being important to dose projections for a member of the public. Because this TRR focuses on the Dose Model, the table only includes parameters included in the Dose Model. For example, each of the analyses addressed in Table 15 identified the infiltration rate as an important parameter, but it is not listed because it is part of the closure cap model rather than the Dose Model and it is not discussed in this TRR. The table lists biosphere parameters that were included in the top twelve PRCC results and top eight SRRC results based on the projected total dose to a member of the public in the 2020 SDF PA and the revised analysis in SRR-CWDA-2021-00047. For the SRCC measurements, Table 15 includes the DOE results based on the dose at 10,000 years because that is the relevant time frame for assessing compliance with the performance objectives of 10 CFR Part 61. Table 15 includes the results based on the total dose. The results based on the peak projected I-129 and Tc-99 doses showed differences in the order of importance of parameters but generally yielded similar results.

Together, the analyses identified six biosphere parameters as having a significant effect on the projected dose to a member of the public: water ingestion rate, garden area, till depth, irrigation rate, fish intake rate, and the soil-to-plant transfer factor for Tc-99. The human intake rate for water and the garden area were identified as important parameters by each of the measurements. Similarly, the soil-to-plant transfer factor for Tc-99 was identified by both the analyses that included it as a stochastic variable (i.e., the last two columns in Table 15); it could not have been identified in the original analysis in the 2020 SDF PA (i.e., the first six columns of Table 15) because the DOE did not treat the transfer factors stochastically in those analyses. The till depth and soil density both were identified by several, but not all, measures. In contrast, the fish intake rate was only identified as an important measure for Sector B. The irrigation rate was only identified as important in one of the measures used in the revised analysis.

In addition to evaluating the PRCC and the SRRC, the DOE evaluated individual realizations with relatively large projected doses to a member of the public. Although the water ingestion pathway contributed more to the projected dose than the produce ingestion pathway for the mean of the realizations, the DOE determined that the produce ingestion pathway contributed more to the projected dose in realizations with the greatest projected dose (see Table 5.7-7 in the 2020 SDF PA). The DOE evaluation of the parameter selection in those realizations emphasized the importance of the water ingestion rate, produce ingestion rate, and garden area to the projected dose. The water and produce ingestion rates directly influence the dose from those exposure pathways by linearly increasing the activity of each radionuclide a human receptor would ingestion. The garden area influences the dose to a member of the public by increasing the modeled local fraction (i.e., contaminated fraction) of produce consumed.

Table 15. Biosphere parameters appearing in the top eight SRCC results or top twelve PRCC results for the total dose to a member of the public (references in table footnotes)

2020 SDF PA						**Revised Analysis (SRR-CWDA-2021-00047)**	
Total Dose Any Sector		**Total Dose Sector B**		**Total Dose Sector D**		**Total Dose Any Sector**	
PRCC[(a)]	**SRCC[(b)]**	**PRCC[(c)]**	**SRCC[(d)]**	**PRCC[(e)]**	**SRCC[(f)]**	**PRCC[(g)]**	**SRCC[(h)]**
Water Intake Rate	Garden Area	Water Intake Rate	Garden Area	Water Intake Rate	Garden Area	Water Intake Rate	Water Intake Rate
Garden Area	Water Intake Rate	Garden Area	Water Intake Rate	Garden Area	Water Intake Rate	Garden Area	Tc Soil-to-Plant Factor
Soil Density	Till Depth	Soil Density	Till Depth	Soil Density	Till Depth	Soil Density	Garden Area
Till Depth		Fish Intake Rate				Tc Soil-to-Plant Transfer Factor	Irrigation Rate

[(a)] adapted from Figure 5.7-10 in the 2020 SDF PA
[(b)] adapted from Table 5.7-8 in the 2020 SDF PA
[(c)] adapted from Figure 5.7-11 in the 2020 SDF PA
[(d)] adapted from Table 5.7-9 in the 2020 SDF PA
[(e)] adapted from Figure 5.7-12 in the 2020 SDF PA
[(f)] adapted from Table 5.7-10 in the 2020 SDF PA
[(g)] adapted from Figure BIO-3.14 in SRR-CWDA-2021-00047
[(h)] adapted from Table BIO-3.6 in SRR-CWDA-2021-00047

The DOE comparison of the results of the 2020 SDF PA and the revised analysis in SRR-CWDA-2021-00047 showed that using stochastic distributions for the soil-to-plant and water-to-fish transfer factors for I-129 and Tc-99 caused a 3 percent increase in the peak of the median dose projection and a 15 percent increase in the peak of the mean dose projection for a member of the public within 10,000 years. Modeling those transfer factors stochastically also increased the range of projected dose results and increased the number of realizations with projections greater than 0.25 mSv/yr (25 mrem/yr). The DOE used stepwise analyses to show that most of that effect could be attributed to the soil-to-plant transfer factor for Tc-99.

3.8.2 Deterministic Sensitivity Analyses

The DOE used the following deterministic sensitivity analyses to evaluate the effects of alternative biosphere assumptions on the projected dose to a human receptor:

- two cases that varied ingestion and inhalation rates
- two cases that use bounding fractions (i.e., 0 percent and 100 percent) for locally produced produce and animal products
- one case that increased the garden area from 100 m^2 to 1000 m^2
- eight cases that considered alternative assumptions for the Kd values used to model radionuclide buildup in site soils due to irrigation with contaminated groundwater

For each of sensitivity cases, the values of all parameters that were not specifically altered were set to their Compliance Case values. The sensitivity cases that affected intake parameters used the Realistic Case and Pessimistic Case values in Section 3.3 through 3.5 in this TRR. The sensitivity cases that changed the values of local fractions only altered the fraction of produce, meat, milk, poultry, eggs, and fish that were raised or caught locally and assumed to be contaminated. The sensitivity analyses for local fractions did not alter the fraction of drinking water from local sources because that fraction was incorporated into the value for water from community sources (see Section 3.5.1). The projected garden area affects the projected dose to a member of the public because the DOE modeled the locally produced fraction of produce the member of the public consumes as related to the garden area with Equation 1 in this TRR. The garden area has a different effect on the projected dose to an inadvertent intruder because it affects the dilution of drill cuttings in garden soil. That relationship is addressed in a TRR on the 2020 SDF PA model for an inadvertent intruder (ML23017A085).

Sensitivity analyses for radionuclide buildup in soil used different sorption coefficients in the buildup calculations than they do in the transport calculations, which accounts for the possibility that the characteristics of the surface soils (e.g., in the top 15 cm tilling depth) are different from the characteristics of deeper soils. For the Compliance Case, the DOE used values for sandy soil to model radionuclide buildup (see Table 8). For the deterministic sensitivity analysis, the DOE used the maximum and minimum sorption coefficients for each radionuclide for any of the soil types listed in Table 4.3-4 of the 2020 SDF PA (i.e., clayey soil, leachate-impacted clayey soil, sandy soil, and leachate-impacted sandy soil). The DOE also used four sets of surface soil sorption coefficients from the site in Olkiluoto, Finland for cesium, chlorine, iodine, niobium, selenium, and technetium (Table 16). The DOE chose values from the Olkiluoto site because it is a humid site with sandy and clayey soil that the DOE determined would be a good analog for SRS.

As noted in the previous paragraph, sensitivity analyses for radionuclide buildup in soil used different sorption coefficients in the buildup calculations than they do in the transport calculations. The DOE did not change any of the sorption coefficients used in the transport calculations in the Vadose Zone Transport Model or the Aquifer Transport Model in the sensitivity analyses for radionuclide buildup in surface soil. For the sensitivity analyses that used the sorption coefficients for soils from Olkiluoto, the DOE set all the surface soil sorption coefficients for all other radionuclides at the maximum values for any of the soil types the DOE modeled in the 2020 SDF PA. The DOE determined that using maximum values would be conservative for this analysis because it would tend to maximize projected buildup of radionuclides in soil.

Table 17, below, provides peak projected doses within 1,000 and 10,000 years of site closure for each of the sensitivity cases and the Compliance Case. For each sensitivity case, only the indicated parameter values changed, and the other parameter values remained set at their Compliance Case values. For each case in Table 17, the peak dose within 1,000 years of closure occurred at 1,000 years and the peak dose within 10,000 years of closure occurred at 10,000 years.

Table 16. Surface soil sorption coefficients from Olkiluoto, Finland (adapted from Table 5.8-25 in the 2020 SDF PA)

Element	Sorption Coefficients Reported for Soil Type (mL/g)			
	Humus, Low Estimates	Humus, Realistic	Top Mineral Soil, Low Estimates	Top Mineral Soil, Realistic
Cesium	100	1,000	860	5,200
Chlorine	0.20	1.5	0.0	0.13
Iodine	10	460	12	32
Niobium	240	870	19,500	100.000
Selenium	57	240	180	250
Technetium	0.0	21	0.0	0.4

Table 17. Deterministic sensitivity case results for a member of the public at the 100-meter well (adapted from Tables 5.8-22 through 5.8-24 and 5.8-26 in the 2020 SDF PA)

Modeling Case	**Projected Peak Dose (mrem/yr)**	
	Within 1,000 years	**Within 10,000 years**
Compliance Case	9.4×10^{-3}	1.2
Realistic human intake values	8.6×10^{-3}	1.1
Pessimistic human intake values	1.3×10^{-2}	1.6
Local fractions = 0	6.7×10^{-3}	0.85
Local fractions = 1	1.6×10^{-2}	1.9
Increase Garden Area by x 10	2.8×10^{-2}	3.1
Surface Kds at maximum values[(a)]	1.2×10^{-2}	1.4
Surface Kds at minimum values[(a)]	8.1×10^{-3}	1.0
Surface Kds at 5x maximum values[(a)]	2.8×10^{-2}	2.8
Surface Kds at 0.2 x minimum values[(a)]	8.0×10^{-3}	1.0
Surface Kds at realistic top soil values from Table 16	9.0×10^{-3}	1.1
Surface Kds at conservative top soil values from Table 16	8.0×10^{-3}	1.0
Surface Kds at realistic humus values from Table 16	5.4×10^{-3}	5.0
Surface Kds at conservative humus values from Table 16	8.0×10^{-3}	1.0

[(a)] maximum and minimum values refer to the maximum and minimum sorption coefficients for each element for any soil type listed in from Table 4.3-4 in the 2020 SDF PA

4.0 NRC Staff Evaluation

4.1 Overview

The NRC staff conducted this review to assess biosphere assumptions the DOE used in modeling to support the 2020 SDF PA. For radionuclide-specific parameters (i.e., transfer coefficients, DCFs), the NRC staff conducted a risk-informed review focused on the values used for I-129 and Tc-99 and the processes the DOE used to select values for other parameters. The DOE's probabilistic sensitivity analyses consistently identified the human water intake rate, garden area, till depth, soil density, and technetium soil-to-plant transfer factor as parameters that have a significant effect on dose. The fish intake rate and irrigation rate also appeared as important parameters in some analyses. The DOE analyses that evaluated parameters that

were significant for realizations with relatively high projected peak doses also identified the produce intake rate as a significant parameter (see Section 4.8.1). The DOE deterministic sensitivity provided additional insights about the relative importance of intake parameters, local fractions, garden area, and sorption coefficients used to model radionuclide buildup in irrigated soil (see Section 4.8.2). The NRC staff used those insights to prioritize areas for its review and to inform recommendations for updating the SDF Monitoring Plan.

As indicated in Section 2.0 of this TRR, the NRC SDF Monitoring Plan does not include a MA for Biosphere. In this review, the NRC staff determined that there was no longer a reason to group MFs related to the Dose Model with MFs related to PA revisions. Therefore, for clarity, the NRC staff recommends that the next revision of the SDF Monitoring Plan include a MA for Biosphere.

> ***DEPM-01*** *The NRC staff recommends opening a MA entitled "Biosphere" for MFs related to biosphere modeling.*

4.2 Critical Group and Exposure Pathways

4.2.1 Critical Group

The NRC staff found the critical group the DOE defined to be acceptable for the purpose of determining compliance with the performance objectives because it includes characteristics and exposure pathways that the NRC staff expects could contribute to be amongst the greatest doses to a member of the public. In general, the NRC staff found that the pathways and parameters the DOE included in the Dose Model were consistent with the definition of the critical group. The NRC staff noted exceptions in the modeling of the inhalation dose (see Sections 4.2.2 and 4.5.1) and the development of human intake parameters for ingestion (see Section 4.5.1); however, the NRC staff does not expect those exceptions to affect the projected dose to a member of the public because they either affected cases other than the Compliance Case or they affected pathways that the NRC staff does not expect to make a significant contribution to the projected dose.

4.2.2 Exposure Pathways

The NRC staff determined that the exposure pathways the DOE modeled in the 2020 SDF PA are acceptable for demonstrating compliance with the performance objective for a member of the public because: (1) the exposure pathways are consistent with the physical properties of the site, (2) the most important exposure pathways are consistent with the definition of the critical groups, and (3) changes in other pathways are unlikely to significantly affect the projected dose. The NRC staff determined that that the DOE inclusion of ingestion, inhalation, and direct exposure was appropriate because the staff expects those pathways could contribute to the dose to a human receptor and the NRC staff expects other exposure routes (e.g., dermal absorption) to cause an insignificant dose.

The NRC staff agrees with the DOE expectation that the main mode of radionuclide transport from the SDF for a member of the public (i.e., without intrusion) would be through groundwater, which could subsequently contaminate surface soil through application of irrigation water and stream water. Therefore, the NRC staff found it was appropriate for the DOE to consider both well water and water taken from McQueen Branch or Upper Three Runs as potential water sources for domestic and agricultural use for a member of the public. For stream water, the

DOE used the projected concentration at the seepline, which the NRC staff found to be conservative because it did not include dilution in the stream. For each year, the DOE chose the concentration from the stream with the greater projected radionuclide concentrations in that year. The NRC staff also found it was appropriate to consider stream water for recreational exposure because the Upper Three Runs and McQueen Branch are the only applicable water sources for recreational exposure near the SDF (i.e., there are no ponds for recreational use near the SDF).

The NRC staff found the exposure pathways for direct exposure to be acceptable because the pathways included exposure to relevant contaminated environmental media (i.e., groundwater, stream water, and soil) for a reasonable set of activities. Specifically, the NRC staff found direct exposure to soil while working with crops or in a garden and direct exposure to water while showering, swimming, and boating to be acceptable because the NRC staff expects those pathways would include the major opportunities for direct exposure to radionuclides. The NRC staff finds the DOE decision to use the DCF for external exposure from soil for the time working in the garden to be acceptable because it is applicable to a person standing on soil and would be conservative for a person working on a piece of farm equipment (e.g., a tractor) because of the added distance from the land surface and partial shielding provided by the equipment.

The NRC staff finds the DOE decision not to include direct exposure to soil during time spent indoors to be acceptable because the NRC staff agrees with the conceptual model that the source of radionuclides to the soil is irrigation water and, therefore, there should not be contaminated soil under the house. In addition, the NRC staff finds the DOE decision not to model direct exposure to radionuclides while a hypothetical receptor is outdoors performing an activity other than working with crops or in a garden to be acceptable because the only source of radionuclides in the soil is irrigation water and, therefore, other parts of the land should not include significant concentrations of radionuclides in the soil. In addition, based on previous experience with PAs for radioactive waste facilities, the NRC staff does not expect submersion in air contaminated with radioactive gasses or suspended particles to contribute a significant dose to a member of the public.

The NRC staff found the exposure pathways for ingestion to be acceptable because the DOE included the ingestion of all materials that the NRC staff expects could make a significant contribution to the ingestion dose for a member of the critical group: water, produce, terrestrial animal products (i.e., beef, milk, poultry, eggs), fish, and soil (including dust). The NRC staff found the DOE decision not to include inadvertent ingestion of stream water modeled with radionuclide concentrations in groundwater at the stream seepline during recreation to be acceptable because the NRC staff agreed with the DOE expectation that inadvertent ingestion of small amounts of water during recreational activities would be negligible compared to the routine ingestion of contaminated well water or stream water for daily drinking water and for preparing food.

The NRC staff found the DOE equations for the dose from ingestion to be acceptable because they accurately reflected the intake of radionuclides in beverages, food, and soil. The NRC staff observed that those equations do not account for changes to radionuclide concentrations during food preparation due to loss of fat or moisture from foods, which can increase radionuclide concentrations, or due to loss of radionuclides during cooking, which can decrease radionuclide concentrations in food. However, the NRC staff determined that there is not enough information

available to determine the effect of those processes on the projected dose to a potential future human receptor. Therefore, the NRC staff found the DOE choice not to include the effects of cooking to be acceptable because it reflected the best available information.

The NRC staff finds the inhalation pathways acceptable for the purpose of determining compliance for an offsite member of the public for the 2020 SDF PA because: (1) the equations include the inhalation of radionuclides on dust and radionuclides in suspended water while irrigating crops, swimming, and showering; and (2) the DOE projects that more volatile radionuclides, such as C-14 and Rn-222, will not have significant concentrations in water at the 100-m well or seepline within 10,000 years of site closure.

In the 2020 SDF PA, the DOE multiplied the moisture content in air during irrigation, swimming, and showering by an ARF of 1×10^{-4}. The NRC staff questioned the application of the ARF to moisture that is already suspended in air instead of an entrainment factor, such as DOE implemented in HNF-SD-WM-TI-707. In the DOE document SRMC-CWDA-2022-00016, Rev. 0, the DOE clarified that the 2020 SDF PA used a different conceptual model for inhalation of radionuclides in air than the DOE used in HNF-SD-WM-TI-707. Specifically, the DOE clarified that the moisture content in air the DOE used in Equations 4.4-174 through 4.4-181 and 4.4-194 through 4.4-197 in the 2020 SDF PA represented the total amount of water in the air and the ARF represented the respirable fraction of that water based on the assumption of water in free fall. The NRC staff determined that mathematical expression was consistent with the conceptual model of inhalation presented used in the 2020 SDF PA. In addition, the NRC staff determined that reasonable changes to the ARF would not significantly increase the projected dose to a member of the public because of the small contribution of inhalation pathways.

In the 2016 Biosphere TRR, the NRC staff noted that volatile radionuclides would partition into the gas phase, which would increase the concentrations that a human receptor could inhale to greater than the particulate concentrations the DOE calculated. In the 2016 Biosphere TRR, the NRC staff noted the effects of volatilization could be enhanced in a hot shower in an enclosed space. The 2016 Biosphere TRR did not resolve that technical question. For the 2020 SDF PA, the NRC staff expects the inclusion of volatilization would not significantly increase the projected dose to a member of the public because the DOE projects that more volatile radionuclides (e.g., C-14 and Rn-222) will not be present in significant concentrations at either the 100-m well or the seepline.

The NRC staff determined that the equations the DOE used to implement the inhalation pathways included time fractions to adjust the inhalation dose to the amounts of time the human receptor participated in specific activities (i.e., working with crops or in a garden, irrigating crops, swimming, and showering). That implementation is inconsistent with the use of an annual average inhalation[3] rate during those activities because the annual average inhalation rate accounts for significant periods of sleep and rest, which would not occur while working with crops, irrigating crops, swimming, and showering. This TRR provides additional information related to that observation in Section 4.5.1.

4.3 Transfer Factors

The NRC staff determined that the values the DOE used for transfer factors are acceptable for use in the 2020 SDF PA for the SDF because the values were obtained from reliable data

[3] The DOE calculated an annual average inhalation rate based on a daily average rate from the EPA Handbook. Daily average rates also include significant periods of sleep and rest.

sources and the literature values were applicable to the physical characteristics of SRS. For transfer factors that were taken directly from the literature without modification (i.e., all factors other than the soil-to-plant transfer factors) the NRC staff confirmed the values for technetium, iodine, and several representative elements matched the literature values according to the DOE document hierarchy in Section 3.3 of this TRR. For the soil-to-plant factors, which are based on literature values for specific types of plants and an assumed crop distribution, the NRC staff reproduced the values for iodine and technetium based on additional information provided by the DOE in SRR-CWDA-2021-00047.

In the 2016 Biosphere TRR, the NRC staff identified three values that appeared to deviate from the document hierarchy:

- feed-to-milk for Tc
- feed-to-meat for Tc
- water-to-fish for Pu

The DOE changed each of these values for the 2020 SDF PA and the NRC staff determined that the revised values correspond to the appropriate values based on the document hierarchy. In addition to those three values, the DOE significantly reduced the feed-to-meat factors for protactinium and samarium, as well as the feed-to-milk factor for silver. The NRC staff determined that the values the DOE used in the 2020 SDF PA were based on the document hierarchy in Section 3.3.

4.4 Crop and Soil Parameters

4.4.1 Crop Parameters

The NRC staff determined the deterministic crop parameters are acceptable for evaluating compliance with the performance objectives in the 2020 SDF PA. For parameters other than garden area, the NRC staff found the values to be acceptable because the DOE chose parameter values from site-specific references or made reasonable assumptions. The NRC staff found the value for garden area to be acceptable for use in the 2020 SDF PA because: (1) the SDF Dose model only uses the garden area to determine the local fraction of produce consumed and (2) the modeled garden area, in conjunction with the modeled garden yield and the equation the DOE used to determine the local fraction of produce consumed resulted in local fractions similar to the EPA Handbook values for the local fractions of produce consumed in households who farm. However, without an additional basis for the garden area, the NRC staff has not made a conclusion about the suitability of the modeled garden area for other purposes. The NRC staff also determined that the probabilistic ranges of crop parameter values the DOE used are acceptable for providing risk insights about the 2020 SDF PA because they included a representative range of parameter values.

The deterministic parameter values the DOE used in the 2020 SDF PA were equal to the values the NRC staff reviewed in the 2016 Biosphere TRR except for the value of the fraction of produce that is leafy, which changed from 0.2 (unitless) to 0.222 (unitless). The DOE based that choice on NRC recommendations in NUREG/CR-5512 vol. 3. In the 2016 Biosphere TRR, the NRC staff determined that the crop parameter values were adequate for use in PAs for the SRS with two exceptions: the fractions of different crops grown and the crop yield. In the 2016 Biosphere TRR, the NRC staff determined that the DOE basis for the fractions of crops of different types grown was not consistent with the definition of the critical group because the

DOE based the crop types on commercial farming, which would not necessarily represent the crops grown by a subsistence farmer. In the 2020 SDF PA, the DOE updated the crop types by combining the commercial values from the SRS region with the generic recommendation in the NRC document NUREG/CR-5512 vol. 3, using the process in the DOE document SRR-CWDA-2018-00057. The NRC staff determined those fractions of different crop types are acceptable because: (1) although the data represent commercial production, the data appear to be the best available data for the region near SRS, and using regional data is especially important for agricultural production and (2) the DOE chose the more conservative of the local data and the NRC generic recommendations for leafy produce, which is important because leafy produce tends to produce a greater dose contribution than other types of produce.

In the 2016 Biosphere TRR, the NRC staff also determined the selection of the garden area was not always consistent with the selection of the crop yield and local fraction of produce consumed in the probabilistic Dose Model. In the 2020 SDF PA, the DOE ensured the parameters were consistent by selecting the local fraction of produce consumed based on Equation 1 in Section 3.4 in this TRR. The NRC staff determined that the equation was acceptable for use in the 2020 SDF PA because: (1) it ensured the values were consistent with other assumptions about the site and (2) the results were generally consistent with data from the EPA Handbook for the fraction of local produce consumed for households who farm.

In the 2016 Biosphere TRR, the NRC staff concluded "NRC staff find[s] the use of 100 m^2 [for the garden area] reasonable given that it is a behavioral parameter and consistent with the default value recommended in NUREG/CR-5512, Vol. 3." However, the default value recommended in NUREG/CR-5512 vol. 3 is 2500 m^2. The DOE used a deterministic sensitivity analysis to determine the effect of variation in garden size on the projected dose to a member of the public. As shown in Section 3.8 of this TRR, increasing the modeled garden area by a factor of 10 increased the projected dose to a member of the public within 10,000 years of site closure by a factor of 2.6. To test the effect of changing the garden size to 2500 m^2, the NRC staff performed a deterministic sensitivity analysis with the DOE Dose Model. That analysis showed that increasing the modeled garden size to 2500 m^2 increased the projected dose by a factor of 5.7. However, using a garden area of 2500 m^2 increased the local fraction of produce used in the model to 6.6, which the NRC staff found to be unrealistic because it would imply that an average member of the critical group consumed 1370 kg/yr of homegrown produce. That ingestion rate (i.e., 1370 kg/yr) is 10 times greater than the mean value in Table 6.87 in NUREG/CR-5512 vol. 3. Because the local fraction of produce consumed is the only parameter the garden area affects in the SDF GoldSim model, uncertainty in the basis for the modeled garden size can be addressed by setting the local fraction to 1.0 and testing the desired homegrown produce ingestion rate. As discussed further in Section 4.5.1, below, using a local fraction of 1.0 and setting the human produce intake rate to the mean value in Table 6.87 in NUREG/CR-5512 vol. 3 (i.e., 133 kg/yr) in a deterministic run of the DOE Dose Model increased the projected dose in the Compliance Case by 28 percent.

The NRC staff determined the irrigation rate is in an acceptable range because the effective rate 25 cm/yr (10 in/yr) is in the range of the irrigation rate for many crops in South Carolina and Georgia (SRMC-CWDA-2022-00003, Rev. 0). In response to an NRC staff RAI question, the DOE confirmed that the SDF Dose Model applied the reported irrigation rate of 2.54 cm/week (1.0 in/week) only during the growing season (SRMC-CWDA-2022-00003, Rev. 0), which is inconsistent with the technical basis provided in the DOE document SRR-CWDA-2021-00072. However, the NRC staff found the original technical basis was conservative (i.e., would tend to overpredict dose) and the revised basis was acceptable because it was consistent with current agricultural practice in the region.

4.4.2 Soil Parameters

The NRC staff determined the deterministic values of soil parameters are acceptable for evaluating compliance with the performance objectives because the DOE chose parameter values from site-specific references or made reasonable assumptions. The NRC staff also determined that the probabilistic ranges of soil parameters the DOE used were acceptable for providing risk insights about the 2020 SDF PA because they included a reasonable range of values.

Both the deterministic and probabilistic parameter values the DOE used in the 2020 SDF PA were equal to the values the NRC staff reviewed in the 2016 Biosphere TRR except for the minimum value of the probabilistic multiplier for the areal density and the dry bulk density of soil, which changed from 0.83 to 0.85. In the 2016 Biosphere TRR, the NRC staff determined that the soil parameter values were adequate for deterministic and probabilistic Dose Modeling for the SRS. The NRC staff expects that the change from 0.83 to 0.85 in the probabilistic multiplier will make an insignificant difference in dose projections for a human receptor because the change in the parameter itself is very small. Although DOE probabilistic uncertainty analyses showed the projected dose to a member of the public was somewhat sensitive to assumptions about the soil density (see Section 3.8.1, above), independent sensitivity analyses the NRC staff conducted did not show a significant change in the projected dose based on the small change in the dry bulk density of soil.

The NRC staff determined the sorption coefficients the DOE used to model soil buildup in the 2020 SDF PA are acceptable for demonstrating compliance with the performance objectives because the DOE based the values on measured soil values from the SRS. In addition, the NRC staff found the probabilistic distributions the DOE used were acceptable for providing risk insights about the 2020 SDF PA because the values were based on variation in an appropriate number of samples (i.e., 27 samples measured in triplicate) for each of ten elements with different sorption characteristics. The NRC staff found that it was appropriate to use distributions to represent the uncertainty in the mean sorption coefficient for each element rather than the variation in the measurements because the NRC staff expects that using the mean sorption coefficient represents the physical averaging of sorption that would apply over the modeled length scales.

Because the samples were taken from the subsurface rather than the surface, the NRC staff questioned whether the samples represented the variation in sorption characteristics of surface samples. To determine the effect increasing the variation could have on projected dose, the NRC staff conducted an independent probabilistic analysis with the DOE Dose Model using double the standard deviation in the sorption coefficients in the soil buildup model. The NRC staff also truncated the distribution at 0 mL/g to prevent numerical errors in the code execution because the code could not accept negative sorption coefficients. Because the Dose Model used groundwater concentration inputs from the Aquifer Transport Model, the NRC staff could change the partition coefficient used to simulate radionuclide buildup in irrigated soil in the Dose Model without affecting the projected radionuclide transport in the vadose zone or aquifer. The analysis showed that modifying the distribution increased the peak of the projected mean dose by 5 percent and increased the 75^{th} percentile by 2 percent. Therefore, the NRC staff does not expect potential increases in the variation in the sorption coefficients in the surface soils to significantly affect the model results.

Although the uncertainty estimates could be improved by creating element-specific uncertainty ranges, the NRC staff does not expect that level of detail is needed to provide risk insights for

radionuclides other than I-129 and Tc-99 because of their relatively small contributions to the projected dose. For I-129 and Tc-99, the NRC staff relied on the deterministic sensitivity analyses the DOE included in the 2020 SDF PA to bound the potential effects of variations in the sorption coefficients in the soil buildup model.

In the 2016 TRR, the NRC staff noted that using the same sorption coefficients to model radionuclide buildup and transport in sandy soils could result in an underestimation of buildup if the DOE chose lower values of the sorption coefficients for conservatism in the transport models. In the 2020 SDF PA, the DOE addressed that concern with deterministic sensitivity analyses that varied the sorption coefficients in the buildup model without changing the sorption coefficients in the transport model. As discussed further in Section 3.8.2, based on those sensitivity analyses, the NRC staff expects that uncertainty in the sorption coefficients for I-129 and Tc-99 in surface soil could affect the projected dose to a human receptor by approximately a factor of two. In combination with other uncertainties in the model, that uncertainty could cause dose projections to approach the performance objectives. In addition, the NRC staff expects that the properties of surface soils could differ from the properties of the subsurface soils the DOE used as a basis for the sorption coefficients in the buildup model (e.g., because of different sand or clay contents or the effects of surface processes). Because of the importance of intake of Tc-99 and I-129 from the plant ingestion pathway to the projected dose to a human receptor in the 2020 SDF PA, the NRC staff makes the following recommendation:

> ***DEPM-02*** *The NRC staff recommends evaluating the differences between sorption of Tc-99 and I-129 in surface and subsurface soil at SRS under a new MF entitled "Kd Values for SRS Soil," which the NRC staff recommended opening in a TRR on SDF hydrogeology and groundwater transport (ML23017A084). The NRC staff recommends considering the effects of differences in surface and subsurface soil (e.g., content of sand and clay), surface processes (e.g., the accumulation of organic material on the soil surface) and the potential effects of agricultural practices (e.g., application of fertilizer or compost).*

4.5 Intake Rates

4.5.1 *Human Intake Rates*

The NRC staff determined that the human intake values the DOE used in the 2020 SDF PA were generally traceable and based on a reliable source (i.e., the EPA Handbook). The NRC staff also found that the DOE considered characteristics of the average member of the critical group, including age, gender, region, rural location, and occupation, when developing intake factors. However, the NRC staff noted some differences between the values the DOE used in the 2020 SDF PA and values from other sources. Those differences are discussed in the relevant subsections below.

The NRC staff found the DOE choice of the EPA Handbook as the basis for human intake factors to be acceptable because it is the best available comprehensive source of human intake factors. Although the EPA has released updates of some of the chapters of the EPA Handbook, the NRC staff found the use of the complete version published in 2011 to be acceptable for consistency among the chapters. In addition, for the most risk-significant intake factors (i.e., water and produce ingestion rates), the NRC staff found the data in the updated chapters were generally consistent with the data in the 2011 version.

The EPA Handbook advises against multiplying intake rates normalized to body weight (e.g., gram per kilogram body weight per day [g/kd-d]) by a hypothetical body weight to calculate intake rates as mass/time (e.g., kg/day or kg per year [kg/yr]). In accord with that recommendation, the DOE only used intake rates that the EPA Handbook expressed in terms of mass per time. However, for some intake rates, that approach limited the data available in the EPA Handbook. For example, for all intake rates except water and soil, the EPA Handbook provides summary recommendations as intake rates normalized to body weight and does not provide summary recommendations in terms of mass per time (e.g., kg/yr). In general, instead of using those recommended values that were normalized to body weight, the DOE combined values from more detailed tables in the EPA Handbook that represented results from individual studies where intake rates were reported as mass per time.

Although that process was consistent with the EPA Handbook guidance against multiplying normalized intake rates by a fixed body weight, it precluded using most of the recommended values in summary tables in the EPA Handbook. Most significantly, using only values provided as mass per time precluded the use of Table 13-1 in the EPA Handbook, which provides normalized intake rates for ingestion of homegrown foods. Instead, as discussed in Section 3.5.1, the DOE used intake rates representing the general population of consumers of each type of food (e.g., produce, meat, milk) and then multiplied those values by the fraction of the food consumed expected to be produced locally. As discussed in additional detail later in this section, the DOE used local fractions for households who farm (or, for fish, for households who fish).

Although the NRC staff found using local fractions for households who farmed or fished was consistent with the definition of the critical group, the results differed significantly from the results in NUREG/CR-5512 vol. 3, Table 6.87, which provides recommended intake rates of homegrown foods for use in decommissioning analyses. Section 6.2.9.3 in NUREG/CR-5512 vol. 3 explains that the authors calculated recommended ingestion rates by multiplying values normalized to body weight in an earlier version of the EPA Exposure Factors Handbook[4] (EPA-600-P-95-002F) by 60 kg. The NUREG indicates that the authors used a mass of 60 kg rather than 70 kg because the survey groups for the normalized intake rates included children.

Each subsection below provides the mean intake rate from NUREG/CR-5512 vol. 3 for context. In some cases, the differences in the ingestion rates were not risk significant because the contributions from the exposure pathways were small (e.g., poultry ingestion). In other cases (e.g., produce ingestion) the differences were more risk significant. In each case, the uncertainty in ingestion rates did not affect the NRC staff's ability to make a decision about compliance with the 10 CFR Part 61 performance objectives because the dose from ingestion pathways is linearly related to the intake rates. However, the NRC staff expects that there could be a difference between intake rates for the general population multiplied by local fractions for households who farm and the actual intake rates of homegrown foods for households who farm and the actual homegrown food ingestion rates because members of households who produce a food (e.g., fruit, vegetables, milk) might consume more of that food than the general population.

[4] NUREG/CR-5512 vol. 3 provides the reference "EPA, 1996" for the version used and also indicates "current version not citable." The NRC staff expect that that version was an external review draft for the EPA Exposure Factors Handbook finalized in 1997. In this TRR, the NRC staff provided the reference for the 1997 final report.

DEPM-03 *The NRC staff recommends opening a new medium-priority MF entitled "Ingestion Pathway Parameters" under the new MA that the NRC staff recommended opening in DEPM-01. The staff recommends using the new MF to evaluate sources of data for intake rates of homegrown or locally produced food, including the applicability of the EPA Exposure Factors Handbook ingestion rates for homegrown foods.*

Water

The NRC staff found the deterministic water intake rate the DOE developed for the Compliance Case to be acceptable for the purpose of determining compliance with the performance objectives because the DOE based the value on data that is consistent with the definition of the critical group. The NRC staff finds the use of "consumer-only" data consistent with the critical group because the DOE defined the critical group as drinking contaminated water. The NRC staff finds the use of the ingestion rate data for "community sources of water" to be acceptable because it is consistent with the EPA Handbook recommendation for site-specific exposure assessments for a hypothetical receptor who consumes contaminated water. The value the DOE selected for the Compliance Case, 505 L/yr, exceeds the mean water intake rate from Table 6.87 in NUREG/CR-5512, vol. 3 (i.e., 487 L/yr).

The NRC staff finds the method the DOE used to create a weighted average for "adults" based on the three age categories for adult water consumption in the EPA Handbook is not technically justified because the DOE weighted the average based on the number of survey respondents in each category and there is no evidence that the age distribution of survey respondents corresponds to the age distribution of individuals near SRS. However, the NRC staff determined that the method was unlikely to cause a significant effect on the dose projections because one age group (i.e., >21) dominated the weighted averages and the NRC staff expects that age group would include most adults in the critical group. In addition, the NRC staff determined that combining data from different surveys for different age groups and consumption percentiles is not statistically justified; however, the NRC staff determined that the result was acceptable because the differences between the two sets of survey data were small and the DOE chose the more conservative (i.e., greater) value in each instance.

The NRC staff found the adjustment factor the DOE developed for the geographic region to be acceptable because it was consistent with the location of the site and was based on applicable survey data. Although the survey combined data for water and juice, the NRC staff agreed with the DOE assessment that the data were suitable for determining regional differences in water intake. The NRC staff determined that the adjustment the DOE applied to account for the human receptor's assumed occupation and recreational activities was acceptable because the DOE chose reasonably high activity levels and used EPA Handbook data for water intake rates corresponding to those activity levels.

For the Realistic Case, the NRC staff found the DOE decision not to apply the adjustment factors for the human receptor's location, occupation, and recreational activities was not justified because those adjustment factors are necessary for the ingestion rate to be consistent with the definition of the critical group (i.e., they are not "safety factors" or a "margin of error" that should be removed for the Realistic Case). However, the value the DOE used for the Realistic Case (i.e., 448 L/yr) is greater than the median intake rate with the adjustment factors applied (i.e., 337 L/yr x 1.08×1.04 = 419 L/yr). Therefore, the NRC staff finds that the deterministic water ingestion rate the DOE used for the Realistic Case is acceptable for the purpose of providing risk insights in deterministic sensitivity analyses.

The NRC staff found the value of 713 L/yr (i.e., 2 L/d) as a deterministic water ingestion rate for the Pessimistic Case to be acceptable because it is a commonly used conservative value that is useful for benchmarking.

The NRC staff found the probabilistic distribution the DOE developed for water intake to be acceptable for providing risk insights for the water ingestion pathway because the distributions provided a sufficient range and distribution of data to show the effect of changing water ingestion rates. In addition, the NRC staff found the DOE process for scaling the data from 2-day averages to annual data to be technically justified because the basis for selecting an autocorrelation factor was transparent and justified. The NRC staff determined the DOE use of consumers-only data for intake of water from community water sources was consistent with the critical group. However, the NRC staff found the decision not to apply the adjustment factors for the human receptor's location, occupation, and recreational activities was not justified because those adjustment factors are necessary for consistency with the definition of the critical group. In addition, the NRC staff found the DOE process for averaging values for different age groups was not technically justified, as discussed above. Because of the importance of the water ingestion pathway to the projected dose to a human receptor in the 2020 SDF PA, the DOE should ensure that the Realistic Case and the probabilistic values are consistent with the definition of the critical group (as the Compliance Case values are).

> ***DEPM-04*** *The NRC staff recommends updating the text of the new MF entitled "Ingestion Pathway Parameters" that the NRC staff recommended opening in DEPM-03 to monitor the DOE use of regional and occupational adjustment factors for human intake parameters in the Realistic Case. The NRC staff also will monitor the DOE use of probabilistic multipliers so the human receptor modeled with those parameter values will be consistent with the definition of the average member of the critical group*.

Soil and Dust

The NRC staff determined the deterministic value the DOE used for soil ingestion is acceptable for demonstrating compliance with the performance objectives because it exceeded the recommended value for the 95th percentile soil and dust consumption in the EPA Handbook. Although the recommended value included both children and adults, and the critical group is defined as representing adults, the NRC staff notes that children generally have a greater soil consumption than adults do. Therefore, the NRC staff determined that exceeding the recommended upper percentile value from the EPA exposure factors handbook is an acceptable value for the deterministic soil and dust ingestion rate. The value used by the DOE in the 2020 SDF PA (1.06 kg/yr) also exceeds the mean value in NUREG/CR-5512 vol. 3 Table 6.87 (0.018 kg/yr).

The NRC staff found the DOE decision not to develop alternative deterministic values (i.e., Realistic Case and Pessimistic Case) or a probabilistic distribution for the soil ingestion rate to be acceptable because the soil ingestion pathway makes a minor contribution to the projected dose in the 2020 SDF PA and previous SDF analyses.

Produce

The NRC staff finds the deterministic value the DOE used for the Compliance Case was based on a reliable data source and was traceable. However, the ingestion rate for local produce the DOE used in the Dose Model (i.e., 207 kg/yr $\times$ 0.26 = 53.8 kg/yr is significantly less than the mean ingestion rate for homegrown produce from Table 6.87 in NUREG/CR-5512, vol. 3 (i.e., 133 kg/yr). To assess the risk-significance of the difference between the value the DOE used and the recommended value in NUREG/CR-5512 vol. 3, the NRC staff ran the DOE Dose

Model with a value of 133 kg/yr and a local fraction of 1.0. That analysis increased the projected dose to a member of the public 100 m from the SDF within 10,000 years of site closure by 28 percent. Because of the risk-significance of the produce ingestion pathway, the NRC staff makes the following recommendation:

> ***DEPM-05*** *The NRC staff recommends updating the text of the new MF entitled "Ingestion Pathway Parameters" that the NRC staff recommended opening in DEPM-03 to monitor the consistency of the modeled produce ingestion rate with the rates of homegrown produce recommended in Chapter 13 of the EPA Handbook.*

The NRC staff agreed with the DOE basis for choosing not to apply adjustments to account for the region (i.e., the South) or for a rural environment, because available data indicate not applying the adjustment was a conservative choice. In addition, the NRC staff found the DOE choice to use the 1994 survey data to be conservative, given the available data in the EPA Handbook. Because of: (1) the importance of the produce ingestion pathway, (2) the age of the data the DOE used in its development of the produce ingestion rate, and (3) the significant difference between the data from the 1970s and 1990s, the NRC staff evaluated whether the 2018 update[5] to the EPA Handbook chapter on fruit and vegetable ingestion provided significantly different values than the version the DOE used. The 2018 update to the EPA Handbook chapter on produce consumption included more recent data from a national survey conducted from 2003-2006. However, the results were only available normalized to the survey respondents' body weight, which was not provided. The EPA Handbook includes the guidance that "converting these intake rates into units of g/day by multiplying by a single average body weight is inappropriate because individual intake rates were indexed to the reported body weights of the survey respondents." Therefore, there was not a way to use the data directly in the DOE 2020 SDF PA. To evaluate whether the 2005-2010 data reflected significant trends in produce consumption compared to the data the DOE used in the 2020 SDF PA, the NRC staff compared consumer-only normalized produce intake rates in the 2005-2010 survey to consumer-only normalized produce intake rates from a 1994-1996 and 1998 data in the EPA Handbook. Based on that comparison, the NRC staff determined that using more recent data for produce consumption would be unlikely to increase the produce intake rates the DOE used in 2020 SDF PA.

The NRC staff found the Realistic Case produce intake rate to be acceptable for providing risk insights for the 2020 SDF PA because the value was based on a reliable source, the development of the value was traceable, and the data were reasonably representative of the critical group. The NRC staff did not find the choice to average the consumption rates for different adult age groups with the same weighting to be statistically justified. However, the NRC staff determined that the age group averaging the DOE used for the 1977-1978 survey would have an insignificant effect on the Realistic Case, which used the average of all four studies, because the differences between age groups were not large and the 1977-1978 study was only one of four in the average. Age group averaging did not affect the Compliance Case intake rate because the Compliance Case intake rate only used the 1994 data.

The NRC staff found the Pessimistic Case produce intake rate to be acceptable for providing risk insights for the 2020 SDF PA because it provided a sufficient range to show the effects of the produce ingestion rate on the model. However, because the DOE based the deterministic Pessimistic Case produce intake rate on the 95th percentile of the stochastic distribution, the

[5] Updates to EPA Handbook chapters have been issued individually. Chapter 9 was updated in 2018.

NRC staff observations related to the stochastic distribution also are relevant to the Pessimistic Case.

The NRC staff found the stochastic distribution for the produce intake rate to be acceptable for providing risk insights for the 2020 SDF PA because it provided a sufficient range to show the effects of the produce ingestion rate on the model. However, the NRC staff observed one step in the development that is likely to underestimate the range and one that is likely to overestimate the range. First, the DOE assumed that the variation in the ingestion rates normalized to body mass (i.e., g produce per kg body mass per day) could be used to represent the range of produce intake rates (i.e., g produce per day). However, the variation in normalized intake rates is likely to underestimate the variation in intake rates because the intake rate is likely to be correlated with body mass (i.e., larger individuals consuming larger portions). Second, the DOE assumed that the variation in the 2-day average normalized intake rates provided by the EPA Handbook represented the variation in the annual averages. However, the EPA Handbook indicates that the variation in the short-term (i.e., 1- or 2-day averages) may overrepresent the variability of long term (e.g., annual) distributions, and that "the upper percentiles shown here may tend to overestimate the corresponding percentiles of the true long-term distribution."

Meat

The NRC staff finds the deterministic value the DOE used to model meat consumption in the Compliance Case to be acceptable for the purpose of demonstrating compliance with the performance objectives because the data were traceable and applicable to the critical group. Although consumers-only values were not available for intakes in dimensions of mass per day, the NRC staff agreed with the DOE determination that the differences between the per capita and consumers-only ingestion rates in the EPA Handbook are insignificant. The DOE based that determination on a comparison of per capita and consumers-only values for meat intake normalized to body weight (i.e., g/kg-day). The locally-produced meat ingestion rate the DOE used in the 2020 SDF PA (i.e., 86.7 kg/yr x 0.319 = 21.9 kg/yr) was less than the mean value recommended in NUREG/CR-5512 vol. 3 (i.e., 39.8). To assess the risk-significance of this difference, the NRC staff conducted a deterministic sensitivity analysis by adjusting the meat ingestion rate to 39.8 kg/yr and the local fraction to 1.0. The change increased the projected dose by 0.9 percent. Therefore, because of the low risk-significance of the difference, and because of the traceable and appropriate technical basis for the values selected by the DOE, the NRC staff finds the values acceptable for use in the Compliance Case of the 2020 SDF PA.

The NRC staff finds the deterministic value in the Pessimistic Case to provide additional information for the purpose of risk-informing evaluation of the meat consumption pathway because the value the DOE used in the Pessimistic Case was traceable and represented a high percentile of meat consumption, which the NRC staff expects will reasonably bound the behavior of the average member of the critical group.

The NRC staff found the probabilistic distribution the DOE used for meat consumption to be suitable for the purpose of risk-informing the evaluation for the meat consumption exposure pathway because the values were traceable provided a sufficient range of values to demonstrate the effect of changing meat intake rates. The NRC staff also determined the DOE process for fitting a probabilistic distribution to the EPA Handbook data was transparent and suitable for the purpose. However, the NRC staff found the decision not to apply the adjustment factors for the human receptor's location, occupation, and recreational activities was not justified because those adjustment factors are necessary for consistency with the definition of the critical group.

Milk
The NRC staff finds the values the DOE used for the ingestion rates for milk are likely to underestimate the projected dose from milk ingestion because they only included fluid milk and did not include other milk products (e.g., cheese, butter, sour cream). Although the volumetric ingestion rate of milk products is typically smaller than the ingestion rate of liquid milk (e.g., see Table 11-10 in the EPA Handbook), preparation of milk products generally concentrates the fluid milk, which can increase the dose contribution from ingesting milk products. Table 75 of IAEA-472 provides values for the retention of radionuclides in food during preparation (F_r) and the concentration that can occur during processing (P_e). In IAEA-472, the overall relationship between the concentration in the raw food and food as consumed is given by:

$$\frac{C_{final}}{C_{original}} = \frac{F_r}{P_e}$$

For example, IAEA-472 provides the example of the concentration of strontium in goat cheese as compared to fluid milk. In that case, IAEA-472 gives a value of F_r = 0.61 (i.e., 39 percent of the strontium is lost from the milk while making goat cheese) and P_e= 0.12 (milk is concentrated by a factor of 1/0.12 = 8.3 when making goat cheese). The result is an overall concentration of a factor of 5 (i.e., 0.61/0.12) for the strontium in goat cheese as compared to fluid milk.

In addition, the NRC staff determined that the ingestion rate for locally-produced milk in the Compliance Case of the Dose Model for the 2020 SDF PA (i.e., 75 L/yr × 0.254 = 19.1 L/yr) is significantly lower than the rate of homegrown milk ingestion recommended in Table 6.21 of NUREG/CR-5512 vol. 3 (i.e., a recommended mean value of 233 L/yr). To assess the risk-significance of the difference, the NRC staff ran the DOE Dose Model with a value of 233 kg/yr and a local fraction of 1.0. That analysis increased the projected peak dose for a member of the public 100 m from the SDF within 10,000 years of site closure 12 percent. Because of the risk-significance of the milk ingestion pathway, the NRC staff makes the following recommendation:

> ***DEMP-06*** *The NRC staff recommends updating the text of the new MF entitled "Ingestion Pathway Parameters" that the NRC staff recommended opening in DEPM-03 to monitor the consistency of the modeled dairy ingestion rate with the rate of ingestion of homegrown dairy products recommended in Chapter 13 of the EPA Handbook, including ingestion of non-liquid dairy products.*

Eggs
The NRC staff finds the values the DOE used for the ingestion rates for eggs in the Compliance Case to be acceptable for demonstrating compliance with the performance objectives because the values were taken from a reliable source and were consistent with the definition of the critical group. The NRC staff finds the use of the average of the four surveys evaluated to be acceptable for the Realistic Case because the NRC staff expects the mean provides the best estimate based on the available data. The NRC staff finds the use of the maximum summary value from the four surveys evaluated to be an acceptable choice for the Compliance Case because it represents a reasonably conservative choice.

Although the NRC staff determined that the ingestion rate for locally-produced eggs used in the Compliance Case of the 2020 SDF PA (i.e., 11 kg/yr × 0.254 = 2.79 kg/yr) was significantly less than the mean ingestion rate for homegrown eggs (19.1 kg/yr) in Table 6.21 in

NUREG/CR-5512 vol. 3, the NRC staff did not find a clear reason for the difference. To assess the risk significance of that difference, the NRC staff performed an independent analysis with the DOE Dose Model in which the NRC staff adjusted the egg ingestion rate to the mean value in Table 6.21 in NUREG/CR-5512 vol. 3 and the local fraction to 1.0. That analysis showed that changing the egg ingestion rate increased the projected peak dose to a member of the public 100 m from the SDF within 10,000 years of site closure by 4 percent. Therefore, because of the low risk-significance of the difference, and because of the traceable and appropriate technical basis for the values selected by the DOE, the NRC staff finds the values acceptable for use in the Compliance Case of the 2020 SDF PA.

The DOE used a value three time the Realistic Case value for the Pessimistic Case. The NRC staff finds the value acceptable because EPA Handbook data for home-produced eggs normalized to body weight (Table 13-40 in the EPA Handbook) exceeds the 95th percentile of egg ingestion.

The NRC staff finds the use of the per capita survey data to be acceptable because data on total dairy intake normalized to body weight in the EPA Handbook suggested there are insignificant differences between the per capita data and consumers-only dairy ingestion rates (i.e., comparison of Tables 11-17 and 11-18)[6].

The NRC staff finds the decision not to develop probabilistic distributions for the egg ingestion rates to be acceptable because the NRC staff agrees with the DOE expectation that egg ingestion are not likely to make a significant contribution to the projected dose to a human receptor near the SDF.

Poultry
The NRC staff finds the value the DOE used for the poultry ingestion rate in the Compliance Case to be acceptable for deterministic modeling for the 2020 SDF PA because the value was taken from a reliable source and was consistent with the definition of the critical group. The NRC staff finds the use of the maximum summary value from the four surveys evaluated, modified by the adjustment factor for the rural setting, to be an acceptable choice for the Compliance Case because it represents a reasonably conservative choice. Although consumers-only values were not available for intakes in dimensions of mass per day, the NRC staff agreed with the DOE determination that the differences between the per capita and consumers-only ingestion rates in the EPA Handbook are insignificant. The DOE based that determination on a comparison of per capita and consumers-only values for meat intake normalized to body weight (i.e., g/kg-day).

Although the NRC staff determined that the ingestion rate for locally produced poultry used in the Compliance Case of the 2020 SDF PA (i.e., 12.1 kg/yr $\times$ 0.319 = 3.86 kg/yr) was significantly less than the mean intake rate for homegrown poultry (25.3 kg/yr) in Table 6.21 in NUREG/CR-5512 vol. 3, the NRC staff did not find a clear reason for the difference. To assess the risk significance of that difference, the NRC staff performed an independent analysis with the DOE Dose Model in which the NRC staff adjusted the poultry ingestion rate to the mean value in Table 6.21 in NUREG/CR-5512 vol. 3 and the local fraction to 1.0. That analysis

[6] NRC staff determined that Table 11-18 in the EPA Handbook appears to be missing a column header for “percent consuming” (e.g., see Table 11-17 in the EPA Handbook) which makes the percentile values for the South appear to differ between the two tables. However, the mean values match for the South in the two tables and the NRC staff believes the percentile values would be very similar as well after accounting for the column heading offset.

showed that changing the poultry ingestion rate increased the dose by less than 1 percent. Therefore, because of the low risk-significance of the difference, and because of the traceable and appropriate technical basis for the values selected by the DOE, the NRC staff finds the value to be acceptable for use in the Compliance Case in the 2020 SDF PA.

The NRC staff finds the use of the average of the four surveys evaluated to be acceptable for the Realistic Case because the NRC staff expects the mean provides the best estimate based on the available data; however, the NRC staff determined it is not justified to exclude the adjustment factor for the rural setting to make the value consistent with the critical group. The NRC staff determined that the value remained acceptable because the difference would make an insignificant change in the projected dose to a human receptor near the SDF because poultry ingestion is not a significant contributor to the projected dose.

The NRC staff found the Pessimistic Case value of three times the Realistic Case to be acceptable to provide risk insights for the review because it provided a sufficient range to demonstrate the effects of changing the poultry ingestion rate. Although the DOE did not provide reasons for selecting a factor of three, the NRC staff expects reasonable alternatives would not change the projected results because poultry ingestion does not make a significant contribution to the projected dose.

The NRC staff finds the decision not to develop probabilistic distributions for the poultry ingestion rates to be acceptable because the NRC staff agrees with the DOE expectation that poultry ingestion is not likely to make a significant contribution to the projected dose to a human receptor near the SDF.

Fish

The NRC staff found that the basis for the deterministic and probabilistic values the DOE used to model fish intake in the 2020 SDF PA was not completely transparent; however, the NRC staff found the values to be acceptable because the NRC staff expect that reasonable variations would not have a significant effect on the projected dose to a human receptor.

In the 2016 Biosphere TRR, the NRC staff determined that the DOE should justify the use of U.S. population survey data in SRS-specific PAs. In the 2020 SDF PA, the DOE used values based on a survey of individuals fishing along the Savannah River near SRS. The NRC staff agrees with the DOE position that a regional adjustment was not needed because the values were based on site-specific data. However, the NRC staff found the origin of the fish in Table 10-81 in the EPA Handbook to be unclear. The title of the table (i.e., “Fishing Patterns and Consumption Rates of People Fishing Along the Savannah River) implies the data represent fish consumption from all sources (i.e., locally-caught and store- or restaurant- bought). However, the title of the original study, “Factors in Exposure Assessment: Ethnic and Socioeconomic Differences in Fishing and Consumption of Fish Caught Along the Savannah River,” implies the survey data pertained to fish caught along the Savannah River (i.e., not total fish consumption from all sources). In addition, Table 10-86 in the EPA Handbook specifies that it provides rates for wild-caught fish based on a survey in South Carolina of individuals who fish. That table provides values of wild-caught fish similar to the rates in Table 10-81 in the EPA Handbook, suggesting that Table 10-81 provides values for wild-caught fish. In that case, the application of a locally caught fraction would incorrectly reduce the values in Table 9 in this TRR.

For comparison, the annual fish intake rate the DOE used in the Compliance Case was less than the median value in Table 6.21 in NUREG/CR-5512 Vol. 3. That is, in the deterministic

Compliance Case the DOE used a deterministic consumption rate 17.8 kg/yr multiplied by a local fraction of 0.325, equal to 5.79 kg/yr, which is less than the median value for homegrown fish recommended in NURG/CR-5512 Vol. 3 (i.e., 7.77) and only 27 percent of the mean (i.e., 21 kg/yr).

Because fish ingestion represents 5 percent of the projected dose to a member of the public at a 100-m well within 10,000 years of site closure (i.e., see Table 5.5-3 of the 2020 SDF PA) a factor of four increase in the projected dose from the fish ingestion pathway could make it a significant exposure pathway. However, the NRC staff agrees with the DOE assessment SRR-CWDA-2013-00058 that an individual is unlikely to intake significant amounts of fish from the streams near the SDF because the fish are likely to be small and scarce, based on site characteristics. Furthermore, any contamination from the SDF that reaches the Savannah River will be significantly diluted. Therefore, the NRC staff concluded that the fish ingestion rate the DOE used in the Compliance Case is unlikely to affect the NRC staff's future conclusion about whether the 2020 SDF PA demonstrates compliance with the 10 CFR Part 61 performance objectives.

Inhalation Rate

The NRC staff finds the deterministic inhalation rate the DOE used in the Compliance Case to be acceptable for the purpose of demonstrating compliance with the performance objectives because independent analyses show the value is likely to represent inhalation exposures for the critical group. However, the NRC staff determined that the basis for the value is not technically justified and the NRC staff disagrees with the DOE characterization of the value as conservative. The NRC staff finds the basis for the DOE value to be inconsistent with the modeled inhalation pathways for a human receptor because the DOE applied an annual average rate, although the model only includes inhalation for specified activities that are inconsistent with that rate. Specifically, the DOE applied an annual average inhalation rate that the DOE calculated by multiplying 365.35 days/yr by selected a daily average value. However, a daily average inhalation rate includes significant periods of sleep and rest. In contrast, the DOE modeled the inhalation dose during specific periods when a human receptor would be active. The DOE modeled dust inhalation only while a human receptor is working with crops or in a garden, (or, for an inadvertent intruder, drilling a well). Similarly, the DOE modeled inhalation of suspended water while a human receptor is irrigating crops, swimming, or showering. Because the Dose Model only includes the contribution of inhalation during the fraction of time the human receptor engages in those activities, including sleep and rest in those periods underestimates the applicable inhalation rate.

Because the DOE chose an upper percentile of the daily average value, the value approximates a mean value that is more applicable to the inhalation pathway in the DOE Dose Model. For example, the inhalation rate the DOE used in the Compliance Case, 8,000 m^3/year, is equal to 1.5×10^{-2} m^3/minute. For comparison, Table 6-2 in the EPA Handbook recommends average values between 1.2×10^{-2} m^3/minute and 1.3×10^{-2} m^3/minute for individuals between 16 and 61 years old engaged in light work and average values between 2.6×10^{-2} m^3/minute and 2.9×10^{-2} m^3/minute for individuals between 16 and 61 years engaged in moderate work. The 95^{th} percentile values for those same age ranges were greater than the value the EPA used: 1.6×10^{-2} m^3/minute to 1.7×10^{-2} m^3/minute for individuals engaged in light work and 3.7×10^{-2} m^3/minute to 4.0×10^{-2} m^3/minute for individuals engaged in moderate work. Therefore, the NRC staff expects the value the DOE selected for the Compliance Case could represent an average member of the critical group in the inhalation pathways the DOE modeled but would not be appropriate for the Pessimistic Case. Similarly, the NRC staff expects the value the DOE used for the Realistic Case underestimates the dose from the inhalation pathway because it is

based on daily averages that incorporate significant periods of sleep and rest, which is inconsistent with the way the Dose Model uses the value.

> ***DEPM-07*** *The NRC staff recommends opening a new low-priority MF entitled "Inhalation Pathway Parameters" in the MA that the NRC staff recommended opening in DEPM-01 to monitor whether inhalation rates in the DOE Dose and Exposure Pathways Model are consistent with the modeled activities (e.g., caring for crops, swimming, and showering).*

Although averaging the age groups with equal weightings does not represent the distribution of ages in the U.S. population or in the vicinity of SRS, the NRC staff expects that changing the weighting of the age groups would not make a large difference in the projected dose because of the small contribution of the inhalation pathway as modeled in the 2020 SDF PA.

The NRC staff finds the DOE decision not to develop a stochastic distribution for the inhalation rate to be acceptable because the NRC staff expects the inhalation pathway will not make a significant contribution to the projected dose to a human receptor.

Local Fractions
In this section, the NRC staff reviewed the basis for the local fractions the DOE used in the 2020 SDF PA. However, as discussed in the introduction to Section 4.5.1 of this TRR, the NRC staff expects there is a difference between the rates of ingestion of homegrown (or locally caught) foods and ingestion rates based on ingestion by the general population multiplied by a local fraction, even if the local fraction represents the critical group (e.g., households who farm). The NRC evaluation of the values used for the local fractions in this section do not imply that the NRC staff recommends using ingestion rates for the general public combined with local fractions for households who farm (or fish).

The NRC finds the deterministic values the DOE used for local fractions of water, produce, and animal products were traceable and represented the critical group. The local fraction of water consumption (i.e., 1.0) is consistent with the use of the EPA Handbook data for use of water from community sources, which only includes use of "local" water. The deterministic values for the local fractions of animal products were based on recommendations from the EPA Handbook for households who farm, which is consistent with the definition of the critical group. In the 2016 Biosphere TRR, the NRC staff recommended that the DOE ensure that the produce ingestion rate was consistent with the modeled garden area and crop yield. In the 2020 SDF PA, the DOE implemented that recommendation by calculating the fraction produce that was grown locally based on garden area and crop yield. The NRC staff determined that the locally grown fraction of produce in the Compliance Case (i.e., 0.266) was similar to the weighted average of the local fractions for fruit and vegetable consumption for households who farm in the EPA Handbook (i.e., 0.275).

Although both the water and produce human intake rates are related to the two most important exposure pathways for a member of the public, the NRC staff found the DOE decisions not to develop probabilistic distributions for the local fraction of water or produce ingested to be acceptable because the potential variation in both parameters is accounted for by other parts of the model. For the local fraction of water ingestion, the variation is incorporated into the stochastic distribution for the intake of water from community sources, which implicitly includes the variation in water from "local" sources because the community sources are assumed to be potentially contaminated. The NRC staff found the DOE decision not to use an independent stochastic distribution for the local fraction of produce consumed to be acceptable because

Equation 1 in this TRR ensured the parameter varied as necessary to remain consistent with the garden area, which was sampled stochastically.

For animal products, the DOE provided stochastic distributions of the local fractions without providing a reason for the shape of the distributions used (i.e., triangular) or the factor of two variation of the mode used to set the minimum and maximum values. The NRC staff finds the triangular shape of the distributions acceptable for probabilistic modeling in the 2020 SDF PA because the NRC staff expects differences in the shape of the distributions of the local fractions of animal products would not change the results of the probabilistic sensitivity or uncertainty analyses due to the relatively small contributions of the animal products pathways.

To assess the range of values the DOE included in the probabilistic distributions for the local fractions of animal products, the NRC staff evaluated data from the EPA Handbook. Although the EPA Handbook did not provide percentile data for the recommended local fractions of meat, milk, fish, poultry, or eggs, it did provide percentile data for locally produced beef, dairy, fish, poultry, and eggs for households who farm (or fish, for fish intake) (i.e., Tables 13-33, 13-25, 13-24, 13-52, and 13-40 in the EPA Handbook). The NRC staff expects that the variation in the amount of locally produced animal products differs from the variation in the locally produced fraction; however, the staff expects the variation in the amount of local animal products consumed will provide a benchmark for the variation in the local fractions. As shown in Table 18, a factor of two variation above the mean exceeded the 75th percentile variation for all consumption rates except for poultry, and a factor of two variation below the median was less than the 25th percentile consumption rate for all products except for eggs and fish.

The NRC staff finds the ranges of the triangular distribution the DOE used for local fractions of animal products to be acceptable for probabilistic modeling in the 2020 SDF PA for two different reasons. For ingestion rate distributions other than for fish ingestion, the NRC staff expects that additional variation would not significantly change the results of the probabilistic sensitivity analysis because consumption of animal products other than fish did not contribute significantly to the projected dose in the 2020 SDF PA. In contrast, in the 2020 SDF PA the DOE projects will contribute 4 percent of the dose to a member of the public at the 100-m well within 10,000 years of site closure. The NRC staff finds the distribution the DOE used for the local fraction of fish ingested to be acceptable for probabilistic modeling for the SDF for two reasons: (1) the variation between the mode and maximum is larger than the ratio between the mode and 75th percentile of locally caught fish in the EPA Handbook, and (2) the assumption that an individual could sustain significant fish ingestion from the tributaries on SRS appears to be conservative based on the size of those tributaries.

Table 18. Variations in the consumption of locally produced animal products for households who farm or fish (Values calculated by NRC staff based on information from the EPA Handbook)

Animal Product	EPA Handbook Table	Median (g/kg-day)	25th percentile ratio to median (unitless)	75th percentile ratio to median (unitless)	90th percentile ratio to median (unitless)
Beef	13-33	2.63	0.55	1.98	3.29
Dairy	13-25	17.1	0.75	1.69	2.88
Fish	13-24	1.63	0.40	1.75	3.25
Poultry	13-52	1.54	0.57	2.65	3.27
Eggs	13-40	0.90	0.40	1.78	2.46

4.5.2 Animal Intake Factors

The NRC staff finds the deterministic values of the animal intake factors the DOE used in the 2020 SDF PA to be acceptable for deterministic modeling because the DOE based values on acceptable references that were applicable to the site and the conceptual model. The references the DOE cited as bases for the deterministic values included data compilations that, in turn, drew information either from NRC documents commonly used in Dose Modeling (e.g., NUREG/CR-5512 Vol. 3.) (ADAMS Accession No. ML052220317) or values based on surveys by agricultural extension programs that were relevant to the area near SRS. For the 2020 SDF PA, the DOE used the same deterministic values for the animal intake factors that the NRC staff reviewed in the 2016 Biosphere TRR. In that review, the NRC staff found those values to be acceptable for deterministic modeling of the biosphere in PA models for the SRS.

The NRC staff finds the DOE choice not to develop probabilistic distributions for water, fodder, or soil intake by animals to be acceptable because the NRC does not expect variation in those parameters to cause significant variation in the projected dose to a human receptor. The DOE previously used stochastic distributions for water, fodder, and soil ingestion by milk and meat cattle in Revision 1 of SRR-CWDA-2013-00058. Although the DOE did not provide a reason for eliminating those stochastic distributions from the 2020 SDF PA model, the NRC staff NRC staff finds the choice to be acceptable because the DOE did not find milk and meat ingestion to be a significant exposure pathway in previous analyses of the SDF and the NRC staff agrees with the DOE expectation that milk and meat ingestion will not be significant exposure pathways.

4.6 External Exposure and Inhalation Parameters

Time Fractions
The NRC staff found the deterministic values of the time fractions that the DOE used in all of the Central Scenario Cases in the 2020 SDF PA be acceptable for demonstrating compliance with the 10 CFR Section 61.41 performance objective because the data were traceable, based on the best available information, and consistent with the definition of the critical group. The NRC staff found the DOE decision not to develop stochastic distributions for the time fractions to be acceptable because, based on the DOE analysis, the NRC staff expects that direct exposure and inhalation pathways will make a much smaller contribution to the projected dose than the water and produce ingestion pathways.

As in the model the NRC staff reviewed for the 2016 Biosphere TRR, the DOE did not include a time fraction for time spent indoors in the Dose Model for the 2020 SDF PA, other than time spent showering. The NRC staff found that approach to be acceptable in the 2016 Biosphere TRR. The NRC staff does not expect direct radiation to make a significant contribution to the projected dose while a member of the public is inside a house for two reasons: (1) the depth of the material under the erosion barrier will provide significant shielding for a house built on top of a disposal structure, and (2) for a member of the public, the NRC staff expects radioactivity on the surface to be limited to the area irrigated with contaminated water (i.e., a garden area). The NRC staff also does not expect inhalation while an individual is in a house to make a significant contribution unless the human receptor is exposed to contaminated waste because the DOE Air Pathways Release Model shows that the projected dose on the land surface from the buried saltstone wasteform is minimal. The NRC staff recommendations related to the inhalation pathway are in Section 4.2.2 in this TRR.

Geometry Factors
The NRC staff found the deterministic values of geometry factors that the DOE used in the Central Scenario Cases in the 2020 SDF PA be acceptable for demonstrating compliance with the 10 CFR Section 61.41 performance objective because the values were either bounding (i.e., for swimming and showering) or appeared to be reasonably conservative based on professional judgment (i.e., for boating). The NRC staff found the DOE decision not to develop stochastic distributions for the geometry factors to be acceptable because, based on the DOE analysis, the NRC staff expects that direct exposure pathway will not make a significant contribution to the projected dose.

ARF and Soil Mass Loading
The NRC staff found the deterministic value the DOE used for soil mass loading while working with crops to be acceptable for demonstrating compliance with 10 CFR Section 61.41 performance objective because the value was traceable and was applicable to rural settings. The NRC staff finds the DOE decision not to develop a stochastic distribution for the soil mass loading to be acceptable because the NRC staff expects that reasonable variations will not significantly affect the projected dose to a member of the public.

As described in Section 4.2.2 of this TRR, the NRC staff did not find the application of an ARF of 1×10^{-4} (unitless) to water that is already suspended in the air to be technically justified. However, the NRC staff determined that using an entrainment factor of 0.01 (unitless), as the DOE did in HNF-SD-WM-TI-707, in place of the unitless ARF, was unlikely to significantly change the projected dose to a human receptor because of the small contribution of the air pathway to the projected dose. Therefore, the NRC staff did not find the ARF the DOE used in the 2020 SDF PA to be technically justified; however, the NRC staff determined the parameter is unlikely to affect an NRC decision about compliance with the performance objectives.

Moisture Contents
The NRC staff found the deterministic values the DOE used to model the moisture content of air while showering because the NRC staff found the value to be traceable and applicable to the modeled activity. For gardening and swimming, the DOE characterized the value of 0.01 kg/m^3 for ambient air as a conservative assumption. Although the NRC staff did not find that value to be traceable, the NRC staff found it to be acceptable because the value appeared to be reasonable based on available data for other environments. The NRC staff found the DOE decision not to develop a stochastic distribution for the moisture content of air to be acceptable because the NRC staff expects that reasonable variations will not significantly affect the projected dose to a member of the public because of the small contribution of inhalation pathways to the projected dose.

4.7 DCFs

The NRC staff found the DCFs the DOE used in the 2020 SDF PA to be acceptable for the purpose of determining compliance with the performance objectives of 10 CFR Part 61 because the DCFs were taken from reliable references, appropriately accounted for contributions from short-lived progeny, and were consistent with the definition of the critical group. The NRC staff found the references to be acceptable because they are generally recognized references that represent the best available information. In addition, the NRC staff found the DOE “Derived Concentration Technical Standard” (DOE-STD-1196-2011) to be an acceptable source of DCFs in the 2016 TRR. For both internal and external DCFs, the NRC staff found that adding the DCFs of the short-lived progeny multiplied by their branching factors was an accurate method of accounting for the dose contribution of those progeny because of the long timeframe of the

analysis (i.e., greater than 100 years). The NRC staff found the use of DCFs for the “Adult” human receptor to be acceptable for the following reasons, as given in the 2016 Biosphere TRR:

> “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). 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.”

However, the NRC staff found the DOE line of reasoning in Section 5.8.6.1 of the 2020 SDF PA that using DCFs for an adult was more conservative than using DCFs for a “reference person” that averaged age groups including children to be inaccurate because DOE-STD-1196-2011 generally shows smaller DCFs for the “adult” category than it does for the “reference person” category.

The NRC staff found the DCFs for external exposure to be acceptable because FGR 15 is a generally accepted source and the specific DCFs the DOE used from that reference were consistent with the exposure pathways the DOE used for the member of the public. For exposure to contaminated soil, the NRC staff found that the DOE selection of DCFs corresponding to 15-cm depth of soil contamination to be acceptable for a member of the public because it is consistent with the conceptual model of soil contamination through irrigation with contaminated water; the NRC staff expects that radionuclides in the saltstone waste form would remain buried too deeply to contribute external dose to a member of the public.

The NRC staff found the DCFs for internal exposure to be acceptable because: (1) no additional information has changed the NRC staff assessment from the 2016 Biosphere TRR that the DOE technical standard DOE-STD-1196-2011 is an acceptable source of DCFs, and (2) the DOE selected appropriate DCFs from that reference. For ingestion, the only radionuclide included in the 2020 SDF PA for which the technical reference (DOE-STD-1196-2011) provided DCFs corresponding to different chemical forms was tritium (H-3) and the DOE used the more restrictive of the two DCFs for the Adult human receptor for that radionuclide. For inhalation, the NRC staff found the DCFs the DOE selected to be acceptable because the DOE either used the absorption fraction recommended as the default for the element in DOE-STD-1196-2011 or the most conservative choice for the radionuclide.

Because of the importance of I-129 for the projected dose for a human receptor, Appendix A of this TRR considers the DCF for ingestion of I-129 in additional detail. Specifically, Appendix A addresses the effect of total iodine ingestion (i.e., I-127 and I-129) on the uptake of iodine by the thyroid. As described in further detail Appendix A, the NRC staff found that the DCF the DOE used to model the dose from ingestion of I-129 is acceptable because the DCF accounts for the expected total iodine intake by a human receptor in the vicinity of the SDF.

4.8 Sensitivity Analyses

4.8.1 Probabilistic Analyses

The NRC staff found the probabilistic sensitivity analyses in the 2020 SDF PA, as supplemented by the analysis in SRR-CWDA-2021-00047, to be acceptable for the purpose of providing risk insights related to the Dose Model for the 2020 SDF PA because the analyses tested appropriate variables over adequate ranges to demonstrate the relative importance of biosphere parameters as compared to other aspects of the PA model. This TRR addresses individual stochastic distributions in the sections related to the applicable parameter. In general, the NRC staff found the distributions to be acceptable for finding risk insights because they included a sufficient range of values and were not excessively broad in a way that would cause risk dilution.

In general, the NRC staff found the selection of variables the DOE included in its probabilistic analysis to be acceptable for the purpose of providing risk insights for the projected dose for a member of the public because the DOE included uncertain parameters that affected key pathways. For the water ingestion pathway, the DOE provided a detailed technical justification for the deterministic values and stochastic parameters for the human water intake rate. That level of detail is risk-informed because the human water intake rate is the key biosphere parameter that affects the projected dose from the water ingestion pathway and the water ingestion pathway is one of the two pathways that dominate the dose projections. This TRR provides additional details of the NRC analysis of the stochastic distribution for the human intake rate of water in Section 4.5.1. For the produce ingestion pathway, the DOE determined that several biosphere parameters had a significant effect on the dose projections, including the produce ingestion rate, garden area, soil density, till depth, and soil-to-plant transfer factor for Tc significantly affected the dose projection. In addition, the DOE found the human intake rate for fish and the irrigation rate could cause a significant effect on the projected dose under some circumstances. In general, the NRC staff found the DOE provided acceptable technical justifications for those parameters, given the level of risk significance. Specific details of the NRC review of the stochastic distributions for those and other biosphere parameters are provided in the sections related to those parameters.

The DOE determination that the soil-to-plant factor for Tc had a significant effect on the projected dose in the revised analysis indicates that it is an important variable for the DOE to include in future SDF PAs. Although the DOE indicated in SRR-CWDA-2021-00047 that there are no engineering controls available to mitigate the uncertainty in transfer factors, the NRC staff determined that it is important to include the uncertainty of transfer factors that affect important exposure pathways (e.g., produce ingestion) to understand the uncertainty in the dose projections. For example, the probabilistic dose projection for a member of the public within 10,000 years in the 2020 SDF PA did not include any projected doses greater than 40 mSv/yr (40 mrem/yr); however, the revised dose projection included realizations up to 1 mSv/yr (100 mrem/yr). The NRC staff agrees with the DOE determination that most of the difference between the probabilistic analysis in the 2020 SDF PA and the revised analysis in SRR-CWDA-2021-00047 could be attributed to the uncertainty in the plant-to-soil transfer factor for Tc-99. That determination emphasizes the importance of including uncertainty in that transfer factor in future PAs for the SDF.

The results of the probabilistic sensitivity analyses were consistent with the site conceptual model and with other model results. For example, each analysis identified the human water intake rate and the garden area as important variables. That result is consistent with the results

of the deterministic and probabilistic models, which identified water and produce ingestion as the two most important exposure pathways for a member of the public. Similarly, both the analyses that included a stochastic distribution for soil-to-plant transfer factors identified it as an important parameter. The till depth and soil density also were identified in several, though not all, of the analyses in which they were included. The till depth affects the dose attributable to the produce ingestion pathway because it decreases the rate at which radionuclides leach from the soil root zone, which increases the effect of radionuclide buildup in soil. The soil density also affects plant uptake of radionuclides from soil because increasing soil density increases the activity that can sorb to the soil in the root zone.

4.6.2 Deterministic Sensitivity Analyses

The NRC staff found that the deterministic sensitivity analyses the DOE performed for the Dose Model provided risk insights for the 2020 SDF PA that added to the insights provided by the probabilistic model. The DOE used the deterministic sensitivity analyses to evaluate the Dose Model in ways that could not be addressed with the probabilistic model. Specifically, the DOE used the deterministic models to evaluate groups of related parameters and to test parameter values that could not easily be tested with the probabilistic model.

Evaluating related groups of parameters provided insights into the effects of categories of parameters that the probabilistic model would address individually. For example, the DOE sensitivity analysis for human intake parameters demonstrated that efforts to refine the human intake parameters would be unlikely to change the projected dose to a human receptor by more than a factor of 2 (Table 17 in this TRR). Those insights allow the NRC staff to risk-inform monitoring efforts for intake parameters compared to monitoring efforts related to other parts of the 2020 SDF PA, both within and outside the Dose Model.

The DOE also used deterministic sensitivity analyses to address features of the Dose Model that required a model implementation that could not easily be tested with the probabilistic model because of relationships between parameters. For example, in the Compliance Case and in the probabilistic model, the DOE based the fraction of local produce on the garden area using Equation 1 in this TRR. In the sensitivity analysis for the fractions of food that were produced locally, the DOE used bounding values of 0 and 1 for locally produced fractions of foods. That analysis showed that the range in the projected dose based on those bounding values is approximately a factor of 2.5 within 10,000 years of closure. The NRC staff expects that range overestimates the likely effect of the variation in locally produced fractions of foods because the locally produced fraction of most food items included in the analysis (e.g., produce, poultry, eggs) is unlikely to reach either 0 or 1.

The sensitivity analyses for the sorption coefficients in the radionuclide buildup model also required making different assumptions about how parameters relate in different parts of the model. Specifically, the sensitivity analysis used different sorption coefficients in surface and subsurface soil. That assumption could not be implemented easily in the Compliance Case or the probabilistic model because those models did not use separate sorption coefficients for the surface soils. Although the DOE indicated that using different sorption coefficients for the surface soils than for other soils represented a conservatism in the sensitivity analysis cases, the NRC staff determined that surface soil properties could differ from subsurface soil properties because of the input of organic material on the surface and because of effects of surface process (e.g., the accumulation of organic matter on the surface) agricultural practices (e.g., irrigation, tilling, application of fertilizers). Therefore, the NRC staff found that it could be

representative of site characteristics to implement different radionuclide sorption coefficients in surface soils than the DOE implemented in the vadose zone.

In the 2016 Biosphere TRR, the NRC staff indicated that selecting sorption coefficient values for the vadose zone "conservatively" to increase radionuclide mobility could have a non-conservative effect on the plant ingestion dose by artificially limiting projected radionuclide buildup in soil. The sensitivity cases for radionuclide buildup provide insights about how various values of sorption coefficients for surface soils could affect the projected dose to a member of the public. For example, using the maximum sorption coefficients for the site instead of the Compliance Case values increased the projected dose to a member of the public by less than 20 percent. Using five times the maximum values to represent sorption in surface soil increased the projected dose by a factor of 2.3 and using a value for humus from an analog site increased the projected dose by a factor of 4.1.

The 2020 SDF PA does not provide a likely range of outcomes for the SDF because (1) the 2020 SDF PA and supporting documents do not propose a likely range for sorption coefficients that account for differences between surface and subsurface soil at the SDF, or (2) likely effects of agricultural practices. The NRC staff shares the DOE expectation that sorption coefficients for humus overstate the likely range of sorption coefficients because the soil in the plant root zone is not likely to be purely made of humus. In contrast, sorption coefficients are known to have large ranges of values, and a value five times the "clayey soil" value for key radionuclides appears to be plausible. The DOE sensitivity analysis showed that an increase of that magnitude could more than double to projected peak dose a member of the public. In addition, the NRC staff expects the information necessary to reduce that uncertainty is available. Because of the importance of intake of Tc-99 and I-129 from the plant ingestion pathway to the projected dose to a human receptor in the 2020 SDF PA, the NRC staff recommends that the DOE evaluate differences between sorption of Tc-99 and I-129 in surface and subsurface soil at SRS in recommendation DEPM-02.

5.0 Teleconference or Meeting

There were no teleconferences or meetings with the DOE related to this TRR.

6.0 Follow-up Actions

There are no specific Follow-up Actions related to this TRR. The NRC staff will continue to monitor the radionuclide inventory in emplaced saltstone under MF 1.01 and the DOE methods to determine inventory under MF 1.02 until the DOE completes saltstone emplacement. The NRC staff recommends updating the SDF Monitoring Plan as described in the Conclusions.

7.0 Conclusions

The NRC staff concluded that the dose and exposure pathways model for in the 2020 SDF PA is acceptable for modeling the projected dose from the SDF for the purpose of the DOE demonstrating compliance with the 10 CFR Section 61.41 performance objective, "Protection of the General Population from Releases of Radioactivity." The NRC staff made that conclusion because the modeled exposure pathways and parameter values were generally consistent with the definition of the average member of the critical group and the site-specific conditions. The NRC staff noted exceptions in Sections 4.2.2 and 4.5.1 of this TRR; however, the NRC staff does not expect those exceptions to significantly affect the projected dose.

The NRC staff did not change the status (open) or priority (low) of MF 10.07, “Calculation of Build-Up in Biosphere Soil,” based on this TRR. The NRC staff also did not change the status (open) or priority (medium) of MF 10.08, “Consumption Factors and Uncertainty Distributions for Transfer Factors,” based on this TRR. The NRC staff recommends that NRC make the following changes to the NRC SDF Monitoring Plan after the NRC staff completes the Technical Evaluation Report:

- **DEPM-01** The NRC staff recommends opening a MA entitled “Biosphere” for MFs related to biosphere modeling.

- **DEPM-02** The NRC staff recommends evaluating the differences between sorption of Tc-99 and I-129 in surface and subsurface soil at SRS under a new MF entitled “Kd Values for SRS Soil,” which the NRC staff recommended opening in a TRR on SDF hydrogeology and groundwater transport (ML23017A084). The NRC staff recommends considering the effects of differences in surface and subsurface soil (e.g., content of sand and clay), surface processes (e.g., the accumulation of organic material on the soil surface) and the potential effects of agricultural practices (e.g., application of fertilizer or compost).

- **DEPM-03** The NRC staff recommends opening a new medium-priority MF entitled “Ingestion Pathway Parameters” under the new MA that the NRC staff recommended opening in DEPM-01. The staff recommends using the new MF to evaluate sources of data for intake rates of homegrown or locally produced food, including the applicability of the EPA Exposure Factors Handbook ingestion rates for homegrown foods.

- **DEPM-04** The NRC staff recommends updating the text of the new MF entitled “Ingestion Pathway Parameters” that the NRC staff recommended opening in DEPM-03 to monitor the DOE use of regional and occupational adjustment factors for human intake parameters in the Realistic Case. The NRC staff also will monitor the DOE use of probabilistic multipliers so the human receptor modeled with those parameter values will be consistent with the definition of the average member of the critical group .

- **DEPM-05** The NRC staff recommends updating the text of the new MF entitled “Ingestion Pathway Parameters” that the NRC staff recommended opening in DEPM-03 to monitor the consistency of the modeled produce ingestion rate with the rates of homegrown produce recommended in Chapter 13 of the EPA Handbook.

- **DEPM-06**The NRC staff recommends updating the text of the new MF entitled “Ingestion Pathway Parameters” that the NRC staff recommended opening in DEPM-03 to monitor the consistency of the modeled dairy ingestion rate with the rate of ingestion of homegrown dairy products recommended in Chapter 13 of the EPA Handbook, including ingestion of non-liquid dairy products.

- **DEPM-07** The NRC staff recommends opening a new low-priority MF entitled “Inhalation Pathway Parameters” in the MA that the NRC staff recommended opening in DEPM-01 to monitor whether inhalation rates in the DOE Dose and Exposure Pathways Model are consistent with the modeled activities (e.g., caring for crops, swimming, and showering).

8.0 References

Center for Nuclear Waste Regulatory Analyses (CNWRA) *Description of Methodology for Biosphere Dose Model BDOSE,* November 2008. ADAMS Accession No. ML083190829.

International Atomic Energy Agency (IAEA), IAEA-472, *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments*, International Atomic Energy Agency, Vienna, Austria, January 2010.

U.S. Department of Energy (DOE), UCRL-76419, Rev. 0, *Resuspension and Redistribution of Plutonium in Soils*, January 1975. ADAMS Accession No. ML22010A042.

___, WSRC-RP-93-1174, Rev. 0, *IRRIDOSE: An Electronic Spreadsheet Designed to Calculate Ingestion Dose Resulting from Irrigating with Savannah River Water,* October 1993. ADAMS Accession No. ML21007A321.

___, DOE-HDBK-3010-94, Rev. 0, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities, Volume 1 - Analysis of Experimental Data,* December 1994. ADAMS Accession No. ML13078A031.

___, PNNL-13421, *A Compendium of Transfer Factors for Agricultural and Animal Products*, June 2003. ADAMS Accession No. ML101600004.

___, HNF-SD-WM-TI-707, Rev. 3, *Exposure Scenarios and Unit Dose Factors for Hanford Tank Waste Performance Assessments*, July 2003. ADAMS Accession No. ML13078A177.

___, WSRC-STI-2006-00198, Rev. 0, *Hydraulic Property Data Package for the E-Area and Z-Area Soils, Cementitious Materials, and Waste Zones, Savannah River Site*, September 2006. ADAMS Accession No. ML101600380.

___, MDL-MGR-MD-000001, Rev. 2, *Biosphere model Report*, August 2007. ADAMS Accession No. ML090720287.

___, WSRC-STI-2007-00184, Rev. 2, *FTF Closure Cap Concept and Infiltration Estimates*, October 2007. ADAMS Accession No. ML111240597.

___, WSRC-STI-2007-00004, Rev. 4, *Baseline Parameter Update for Human Health Input and Transfer Factors for Radiological Performance Assessments at the Savannah River Site,* June 2008. ADAMS Accession No. ML101600382.

___, SRNL-STI-2010-00447, Rev. 0, *Land and Water Use Characteristics and Human Health Input Parameters for Use in Environmental Dosimetry and Risk Assessments at the Savannah River Site*, August 2010. ADAMS Accession No. ML111220416.

___, DOE-STD-1196-2011, Rev. 0, *Derived Concentration Technical Standard*, April 2011. ADAMS Accession No. ML14007A665.

___, SRNL-STI-2010-00128, Rev. 1, *Performance Assessment for the H-Area Tank Farm at the Savannah River Site,* November 2012. ADAMS Accession No. ML13045A499.

___, SRNL-STI-2013-00115, Rev. 0, *Site-Specific Reference Person Parameters and Derived Concentration Standards for the Savannah River Site, Savannah River Site*, March 2013. ADAMS Accession No. ML22047A271.

___, SRR-CWDA-2013-00058, Rev. 0, *Dose Calculation Methodology for Liquid Waste Performance Assessments at the Savannah River Site*, May 2013. ADAMS Accession No. ML14008A055.

___, SRR-CWDA-2013-00062, Rev. 2, *FY 2013 Special Analysis for the Saltstone Disposal Facility at the Savannah River Site*, October 2013. ADAMS Accession No. ML14002A069.

___, SRR-CWDA-2013-00058, Rev. 1, *Dose Calculation Methodology for Liquid Waste Performance Assessments at the Savannah River Site,* July 2013. ADAMS Accession No. ML16167A295.

___, SRNL-STI-2015-00056, Rev. 0, *Dose Calculation Methodology and Data for Solid Waste Performance Assessment and Composite Analysis at the Savannah River Site*, April 2015. ADAMS Accession No. ML22010A038.

___, SRNL-STI-2009-00473, Rev. 1, *Geochemical Data Package for Performance Assessment Calculations Related to the Savannah River Site*, July 2016. ADAMS Accession No. ML17047A417.

___, SRR-CWDA-2013-00058, Rev. 2, *Dose Calculation Methodology for Liquid Waste Performance Assessments at the Savannah River Site*, January 2019. ADAMS Accession No. ML20206L207.

___, SRR-CWDA-2014-00006, Rev. 2, *Fiscal Year 2014 Special Analysis for the Saltstone Disposal Facility at the Savannah River Site*, September 2014. ADAMS Accession No. ML15097A366.

___, SRR-CWDA-2016-00072, Rev. 0, *Fiscal Year 2016 Special Analysis for the Saltstone Disposal Facility*, October 2016. ADAMS Accession No. ML18081A262.

___, SRR-CWDA-2017-00019, Rev. 0, *Updated Sorption Constants for use in Performance Assessment Modeling, Savannah River Site*, February 2017. ADAMS Accession No. ML20279A784

___, SRR-CWDA-2018-00057, Rev. 0, *Recommended Yield Percentage of Locally Grown Produce in the Savannah River Site Area for Use in Dose Calculations to Support Liquid Waste Performance Assessments*, Savannah River Site, Aiken, SC, September 2018. ADAMS Accession No. ML122035A155.

___, SRR-CWDA-2019-00001, Rev. 0, *Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site*. March 2, 2020. ADAMS Accession No. ML20190A056.

___, SRR-CWDA-2021-00047, Rev. 1, *Comment Response Matrix for the First Set of U.S. NRC Staff Requests for Additional Information on the Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site*, July 2021. ADAMS Accession No. ML21201A247.

___, SRR-CWDA-2021-00072, Rev. 0, *Comment Response Matrix for the Second Set of U.S. Nuclear Regulatory Commission Staff Requests for Additional Information on the Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site,* August 2021. ADAMS Accession No. ML21231A201.

U.S. Environmental Protection Agency (EPA), EPA-600-P-95-002F, *Exposure Factors Handbook*, August 1997. ADAMS Accession No. ML13078A066.

___, EPA-600-R-090-052F, *Exposure Factors Handbook*, September 2011. ADAMS Accession No. ML14007A666.

___, EPA-520/1-88-020, *Federal Guidance Report No. 11: Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, September 1988.

___, EPA-402/R19/002, *Federal Guidance Report No. 15: Federal Guidance Report No. 15: External Exposure to Radionuclides in Air, Water and Soil*, August 2019.

U.S. Nuclear Regulatory Commission (NRC), NUREG/CR-5512, Vol. 3, *Residual Radioactive Contamination from Decommissioning: Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent, Final Report*, October 1992. ADAMS Accession No. ML082460902.

___, *Technical Review of Dose Calculation Methodology for Liquid Waste Performance Assessments at the Savannah River Site,* December 2016. ADAMS Accession No. ML16277A060.

___, *NRC Plan for Monitoring Disposal Actions Taken by the U.S. Department of Energy at the Savannah River Site Saltstone Disposal Facility in Accordance with the National Defense Authorization Act for Fiscal Year 2005, Rev 1,* September 2013. ADAMS Accession No. ML13100A113.

___, *NRC Staff Comments and Requests for Additional Information on the Fiscal Year 2013 Special Analysis for the Saltstone Disposal Facility at the Savannah River Site,* June 2014. ADAMS Accession No. ML14148A153.

___, *NRC Staff Request for Additional Information on the Fiscal Year 2014 Special Analysis for the Saltstone Disposal Facility at the Savannah River Site,* June 2015. ADAMS Accession No. ML15161A541.

Appendix A

Potential Limitations to Iodine-129 Dose for Saltstone Disposal Facility Performance Assessment

POTENTIAL LIMITATIONS TO IODINE-129 DOSE FOR SALTSTONE DISPOSAL FACILITY PERFORMANCE ASSESSMENT

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1.0 Purpose

The purpose of this appendix is to evaluate a possible limitation on the projected dose from I-129 in the U.S. Department of Energy (DOE) 2020 Performance Assessment (PA) for the Saltstone Disposal Facility (SDF) at the Savannah River Site (SRS). The report evaluates how the DOE accounts for the dilution of iodine-129 (I-129) by stable iodine (I-127) when calculating dose. It also addresses the applicability of the dose conversion factors (DCFs) the DOE used to calculate the projected dose from I-129 ingestion.

2. Background

2.1 Iodine Intake, Uptake, and Isotopic Dilution

The projected dose from ingestion of a radionuclide is calculated based on both biokinetic and dosimetric models. Biokinetic models simulate the retention and distribution of a radionuclide in the body. Dosimetric models simulate the energy deposited in tissues. To simplify the calculation of dose based on radionuclide ingestion or inhalation, it is common to develop DCFs that use both biokinetic and dosimetric models, with certain reference assumptions, to estimate the dose per unit quantity of a radionuclide inhaled or ingested. This appendix addresses certain biokinetic and dosimetric considerations related to the ingestion of I-129, which the DOE expects to be one of the two radionuclides that dominate the projected dose from the SDF.

Because biometric models generally depend on the chemical and physical properties of an element rather than the radiological properties of a specific isotope of the element, this appendix distinguishes between the general term “iodine” and references to specific isotopes. Throughout this appendix, the word “iodine” will be used to refer to properties common to all isotopes of iodine (e.g., uptake by the thyroid) and the designation I-129 will be used to refer to concentrations or properties of that isotope. The term “stable iodine” will generally be used to refer to dietary intake of I-127 because specific isotopic measurements generally were not made but could be assumed to be I-127.

Biokinetic models used to project radiation dose from internal exposure distinguish between radionuclide intake and uptake. The International Commission on Radiation Protection (ICRP) defines intake as “activity that enters the respiratory tract or gastrointestinal tract from the environment” and uptake as “the activity that enters the body fluids from the respiratory tract, gastrointestinal tract or through the skin” (ICRP Publication 71). For ingested radionuclides, the ICRP also defined the fractional absorption in the gastrointestinal tract (f_1) as “the fraction of an element directly absorbed from the gut to body fluids” (ICRP 71). The ICRP consistently recommends that iodine ingested in food should be assigned an f_1 value of 1 (e.g., see ICRP 26, ICRP 56, ICRP 72). More recently, in ICRP 100, the ICRP defined the alimentary

tract transfer factor (f_A) as “the fraction of activity entering the alimentary tract that is absorbed to blood, taking no account of losses due to radioactive decay or endogenous input of activity into the tract.” The most recent value of f_A for ingestion of iodine in food is given in ICRP 137, which recommends a value of 1.

Once absorbed into the body, iodine is selectively taken up by the thyroid and the remainder is excreted. Because of that selective uptake, and because I-129 decays with low-energy beta emission, the radiological dose from I-129 is almost entirely limited to the thyroid. However, the capacity of the thyroid to take up iodine is limited, so the fraction of iodine in the body that the thyroid can take up decreases with the amount of iodine in the body. Because relative thyroid uptake of iodine isotopes is proportional to the isotopes’ relative abundance in the body, stable iodine (i.e., I-127) can compete with I-129 for the limited capacity of the thyroid to take up iodine causing “isotopic dilution.”

For example, National Council on Radiation Protection and Measurements Report 159 provides Equation A-1, below, to model the relationship between thyroid uptake of radioactive iodine ingested with I-127 within 24 hours:

$$percent\ uptake\ of\ radioactive\ iodine\ = 8.64 \times (iodine\ dose\ in\ milligrams)^{-0.59} \quad \text{Eqn. A-1}$$

where 8.64 and 0.59 are unitless empirical parameters (Figure A-1). Equation A-1 was originally developed by Blum and Eisenbud (1967) to model the 24-hour fractional uptake of I-131 administered with I-127 for an adult who regularly consumes 150 µg/day of iodine. In the experiments Blum and Eisenbud performed, I-131 accounted for a negligible amount of the mass of the iodine dose. In contrast, NCRP Report 159 applies Equation A-1 to thyroid uptake of I-129 and notes that, because of the low specific activity of I-129, the mass of I-129 must be included with I-127 in calculating the “iodine dose” on the right-hand side of Equation A-1. NCRP Report 159 further generalizes Equation A-1 to project the fractional uptake of radioactive iodine by the thyroid as a function of the daily dietary intake of iodine.

Similarly, Zvonova (1989) proposed the following relationship (Equation A-2) between iodine intake expressed in µg/day and the iodine uptake fraction:

$$f = \frac{85\ \mu g/day}{85\ \mu g/day\ + intake\ in\ \mu g/day} \quad \text{Eqn. A-2}$$

where f is the equilibrium fraction of iodine taken up by the thyroid. Figure A-1 compares this relationship with the relationship provided by Blum and Eisenbud (1967).

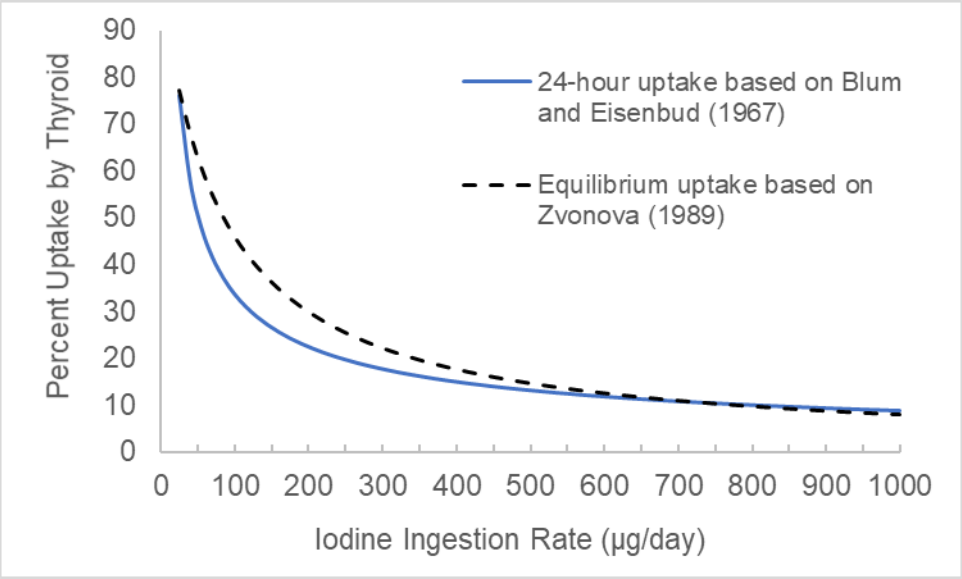

Figure A-1. Thyroid uptake of iodine as a function of the iodine ingestion rate based on the work of Blum and Eisenbud (1967) and Zvonova (1989)

2.2 Previous DOE Consideration of I-129 Uptake and Isotopic Dilution

The Center for Nuclear Waste Regulatory Analyses (CNWRA) and the U.S. Nuclear Regulatory Commission (NRC) staffs reviewed two DOE reports that evaluated whether to account for reduced uptake of iodine at elevated iodine intake levels in PAs for DOE sites (WSRC-RP-98-01352; SRNL-STI-2009-00463) as well as key technical references for those DOE reports (ICRP, 1989; Zvonova, 1989; Moeller et al., 2004; Moeller et al., 2005).

In WSRC-RP-98-01352, the DOE evaluated the basis for the DCF the DOE used at that time for ingestion of I-129. The DOE concluded that the DCF appropriately accounted for the expected ingestion of stable iodine and was unlikely to require further adjustment under conditions relevant to PAs for DOE sites. In addition, the DOE determined that the dose due to ingestion of I-129 might be less sensitive to increased iodine ingestion than the decreasing percent uptake into the thyroid (e.g., Figure A-1) might suggest because increased iodine ingestion also affects the size of the thyroid. Based on the work of Zvonova (1989), the DOE noted that at greater iodine ingestion rates, the thyroid tends to shrink, which allows the low-energy beta emissions of I-129 to affect more of the thyroid tissue. The practical implication is that even if increased intake of stable iodine decreases I-129 uptake by the thyroid (as in Figure A-1), the dose caused by I-129 might not decrease as much as thyroid uptake of iodine decreases because the same amount of I-129 causes more damage in a smaller thyroid. Because the DCF already accounted for stable iodine ingestion and the DOE believed the DCF might not be sensitive to increases in stable iodine ingestion, the DOE concluded that it would not be appropriate to reduce the projected dose from I-129 based on stable iodine ingestion.

In SRNL-STI-2009-00463, the DOE reviewed that decision and supported the conclusion that isotopic dilution was unlikely to reduce the projected dose from I-129 at environmentally relevant concentrations of I-127 and I-129.

2.3 Recommendations of the ICRP

Because iodine is a nutrient present in all human diets, any calculation of dose from ingestion of radioactive iodine must account for competition from stable iodine. To develop DCFs for iodine ingestion, the ICRP established 200 µg/day as the assumed rate of dietary intake for stable iodine for the "Reference Man" in ICRP Publication 23. In ICRP Publication 23, the Reference Man assumptions also included the iodine content of the body (11 mg) and thyroid (10 mg). ICRP Publication 30 also used a thyroid mass of 20 g with a fractional uptake to the thyroid of 0.3.

Because the DCFs in Federal Guidance Report (FGR) 11 are based on ICRP Publication 26 and Publication 30 recommendations, they implicitly incorporate the assumed 200 µg/day stable iodine ingestion rate. The ICRP continued to use the 0.3 assumed fractional uptake of iodine into the thyroid in subsequent publications, including: (1) ICRP Publication 56, which used an updated biokinetic model, (2) ICRP Publication 67, which revised the ingestion DCFs for iodine to account for the updated tissue weighting factors in ICRP Publication 60, and (3) ICRP Publication 72, which provides age-dependent DCFs for members of the public from the intake of radionuclides.

More recently, the ICRP updated the biokinetic model for iodine and redefined the assumed ingestion rate for iodine (i.e., the "reference values" used in the biokinetic model to calculate the retention and distribution of radioactive iodine in the body). In ICRP Publication 137, the ICRP established reference values for dietary intake of stable iodine as 190 µg/day for a man, 130 µg/day for a woman, and 160 µg/day as a gender-averaged value. As shown in Table A-1, below, these changing assumptions have not changed the recommended DCFs for I-129 significantly.

3.0 Applicability to the SRS

As shown in Table A-1, in the 2020 SDF PA, the DOE used a DCF for I-129 ingestion that is nearly identical to the value recommended in ICRP Publication 72. Therefore, the applicability of those DCFs to a PA for the SDF depends largely on whether there are significant site-specific deviations from the stable iodine ingestion the ICRP assumed in the development of the ICRP Publication 72 DCF for ingested iodine for a gender-averaged adult. The CNWRA and NRC staffs considered three sources of stable iodine near SRS: (1) naturally occurring iodine in SRS groundwater, (2) iodine leached from SDF salt waste, and (3) dietary iodine. As described in further detail in Sections 3.1.1 through 3.1.3, the NRC staff expects stable iodine consumption from food and beverages to be the largest contributor to iodine consumption.

3.1 Iodine intake from groundwater

The DOE document SRNL-STI-2009-00463 states that the highest natural I-127 groundwater concentration at SRS is 14 µg/L. Additional studies of SRS groundwaters from outside contaminant plumes report I-127 concentrations ranging from 4.2 µg/L to 8.6 µg/L (Otosaka et al., 2011; Schwehr et al., 2014). Therefore, an individual who drinks approximately 2 L/day of water from the SRS would ingest approximately 8 µg/d to 30 µg/d of naturally occurring stable iodine from the groundwater.

Table A-1. Dose conversion factors for iodine ingestion

DCF Reference	Biokinetic Model for Iodine Metabolism	Assumed Total Iodine Ingestion (µg/d)	Reference for Assumed Total Iodine Ingestion	I-129 Ingestion DCF (Sv/Bq) [(a)]
FGR 11	ICRP 30	200	ICRP 23 Reference Man	7.46×10^{-8}
ICRP Publication 72	ICRP 56	(b)	(b)	1.1×10^{-7}
DOE 2020 SDF PA	ICRP 56 model with ICRP 89 physiological parameters	(b)	(b)	1.08×10^{-7} [(c)]
ICRP Publication 137	Leggett (2010)	160	ICRP 137 Gender-Averaged Adult	9.4×10^{-8}

[(a)] This column reports values to the number of significant digits provided in the reference.
[(b)] The ICRP Publications 56, 72, and 89 do not indicate the assumed total intake of iodine. However, ICRP Publication 56 indicates it uses 0.3 for the fractional uptake of iodine to the thyroid for an adult. That fractional uptake is equal to the value used in ICRP 26, indicating similar assumed levels of total iodine intake.
[(c)] The DOE provided a value of 4.00×10^{-4} mrem/pCi, which the NRC staff converted to Sv/Bq by dividing by 3,700.

Greater I-127 concentrations occur in contaminant plumes. For example, the DOE document WSRC-RP-98-01352 lists I-127 concentrations up to 1,190 µg/L in wells near the "old burial ground." An individual consuming 2 L/d of that groundwater would consume 2,380 µg/d of stable iodine, which would be expected to have a significant effect on thyroid uptake of iodine (see Figure A-1). In WSRC-RP-98-01352, the groundwater well with 1,190 µg/L I-127 also had 0.068 µg/L (12 pCi/L) I-129. Using the ICRP 72 DCF for I-129 ingestion would project an individual consuming 2 L/d of that groundwater would receive a dose of 0.035 mSv/yr (3.5 mrem/yr); however, the DCF is likely to overpredict that result because it does not account for the effect of the I-127 on thyroid uptake of iodine. However, this I-127 ingestion rate far exceed the rates considered in the DOE analyses of the limits of isotope dilution discussed in Section 2.2 and in the 2020 SDF PA.

3.2 Stable iodine in SDF salt waste

The solid components of saltstone (i.e., Portland cement, fly ash, and blast furnace slag) are all made at sufficiently high temperature to volatilize and release iodine. Therefore, the NRC and CNWRA staffs expect they will not contribute significantly to stable iodine leached from the SDF.

The other major component of saltstone is the treated salt waste solution. The DOE document SRR-CWDA-2021-00047, Rev. 1 indicated the DOE projects that leaching from the SDF will increase the peak total iodine concentration (i.e., the sum of I-129 and I-127) at 100 m from the SDF by 0.11 µg/L. Compared to the 4.8 µg/L to 14 µg/L reported range of naturally occurring I-127 in SRS groundwater (see Section 3.1 of this Appendix), iodine leached from the SDF will have a negligible effect on the total iodine in groundwater in the vicinity of the SDF.

3.3 Dietary Intake

Dietary consumption of iodine depends on geography, regional dietary habits, and food production practices. Geography can affect dietary iodine intake because iodine is unevenly distributed in soils and, therefore, in plants grown in those soils. Regional dietary habits can affect iodine consumption because the average intake of foods that are naturally high in iodine (e.g., seaweed, fish, and eggs) varies with location. Food production practices can affect iodine consumption either intentionally (e.g., iodizing salt) or unintentionally. Examples of unintentional introduction of iodine into foods include the use of iodophors (i.e., iodine-based sanitizing agents) in the dairy industry (National Academies, 2004) and the use of iodate-based dough conditioners in commercial bread making (U.S. Department of Agriculture, 2020).

Because dietary habits and food production practices can change with time, it is important to assess recent data and trends in iodine consumption. In the U.S., data on the dietary intake of iodine is made available by the National Center for Health Statistics (NCHS). The NCHS obtains that information by periodically conducting a National Health and Nutrition Examination Survey (NHANES). Trends in iodine consumption can be found by comparing results from NHANES reports from different time periods. For example, comparison of NHANES studies indicates that the average daily iodine intake in the U.S. decreased from about 300 µg/d in 1971-1974 to about 150 µg/d in 1988-1994 (Hollowell et al., 1998). An analysis of more recent NHANES data (Juan et al., 2016) estimated a median iodine intake of 350 µg/d in U.S. males from 31 to 50 years old and a median intake of 289 µg/d in U.S. females from 31 to 50 years old.

Although iodized salt can contribute to dietary iodine intake, the National Institutes of Health (NIH) indicates that trends in sodium consumption in the United States are not a reliable indicator of trends in iodine consumption because most sodium intake in the U.S. is attributable to consumption of processed foods, which are typically made with un-iodized salt (NIH, 2021). Similarly, an analysis of NHANES III data showed dairy intake, but not salt intake, had a statistically significant correlation with iodine intake (Caldwell et al., 2013).

Regional data from the NHANES III report reflecting surveys from 1988 to 1994 showed the South had a median iodine intake 6 percent greater than the national average (Hollowell et al., 1998). The same study did not find a statistical difference between iodine intake in residents in metropolitan and non-metropolitan areas.

4.0 Discussion

In the 2020 SDF PA, the DOE used a DCF for iodine ingestion that is within two percent of the ICRP 72 recommended DCF for iodine ingestion by adults. The ICRP based that value on the assumption that 30 percent of the iodine in the blood is taken up by thyroid (i.e., fractional uptake of 0.3). The ICRP developed that assumption to be consistent with an assumed 200 µg/day ingestion of stable iodine by Reference Man (ICRP 23, ICRP 30). Iodine intakes less than the reference value would tend to lead to greater fractional uptake by the thyroid and iodine intakes greater than the reference value would tend to lead to lower fractional uptake.

Because of the influence of stable iodine ingestion on the uptake of I-129 by the thyroid, the NRC and CNWRA staffs assessed potential sources of stable iodine for a human receptor near the SDF. As indicated in Section 3, the contributions of naturally occurring iodine and iodine leached from the SDF are expected to be small compared to potential variations in dietary

sources of iodine. Although much larger amounts of iodine ingestion are possible if drinking water is taken from a contaminant plume elsewhere on SRS (see Section 3.1), those concentrations are not present at the 100-m boundary of SDF. Therefore, dietary intake is the only source of stable iodine that the NRC and CNWRA staffs expect to significantly affect the projected dose to a member of the public from the SDF.

The average dietary intake of stable iodine in the U.S. has changed significantly in the past five decades, from about 300 µg/d in the early 1970s, to only 150 µg/d in the mid-1980s, back to approximately 300 µg/d for women and 350 µg/d for men in the early 2010s. As shown in Figure A-1, those variations might be expected to cause the equilibrium fractional uptake of iodine by the thyroid to vary between 0.2 to 0.4. The effect on the dose from I-129 ingestion could be somewhat smaller than suggested by that range in fractional uptake (i.e., 0.2 to 0.4) because of the compensating effect on thyroid size (see Section 2.2 in this Appendix). The average uptake the ICRP assumed in its development of a DCF for I-129 was in the midpoint of that range (i.e., 0.3).

Measured differences between national averages of iodine intake and averages for the U.S. South or non-metropolitan areas were much smaller than the variations of the national average of stable iodine ingestion over time.

5.0 Conclusions

The NRC staff has not found evidence to support significantly greater dietary iodine ingestion in the vicinity of SRS compared to the ingestion that is accounted for in the iodine ingestion DCFs the DOE used in the 2020 SDF PA. Therefore, the NRC staff has determined that the DCF for I-129 ingestion that the DOE used in the 2020 SDF PA is appropriate.

6.0 References

Blum, M., Eisenbud, M., Vol., *Reduction of Thyroid Irradiation From 131-I by Potassium Iodide,* Journal of the American Medical Association, Vol. 19(12), p.1036-1040. June 1967.

Caldwell, K.L., Pan, Y., Mortensen, M.E., Makhmudov, A., Merrill, L., Moye, J. *Iodine Status in Pregnant Women in the National Children's Study and in U.S. Women (15–44 Years), National Health and Nutrition Examination Survey 2005–2010,* Thyroid, Vol. 23(8), p. 927-937. August 2013.

Hollowell, J.G., Staehling, N.M., Hannon, W.H., Flanders, D. W., Gunter, E.W., Maberly, G.F., Braverman, L.E., Pino, S., Miller, D.T., Garbe, P.L., DeLozier, D.M., and Jackson, R.J. *Iodine Nutrition in the United States: Trends and Public Health Implications. Iodine Excretion Data from NHANES I and NHANES III (1971-1974 and 1988-1994),* Journal of Clinical Endocrinology and Metabolism*,* Vol. 83 p. 3401-3410, October 1998.

International Commission on Radiation Protection (ICRP), Publication 23, *Report of the Task Group on Reference Man*, Annals of the ICRP, Vol. OS-23(1), January 1975.

Juan, W-Y., Trumbo, P.R., Spungen, J.H., Spungen, Dwyer, J.T., Carriquiry, A.L., Zimmerman, T.P., Swanson, C.A., Murphy, S.P., *Comparison Of 2 Methods for Estimating the Prevalences of Inadequate and Excessive Iodine Intakes,* American Journal of Clinical Nutrition, Vol. 104 (Suppl.), p. 888S–97S, 2016.

Moeller, D.W., Ryan, M.T., *Limitations on Upper Bound Dose to Adults Due to Intake of ^{129}I in Drinking Water and a Total Diet—Implications Relative to the Proposed Yucca Mountain High Level Radioactive Waste Repository*, Health Physics, Vol. 86, p. 586–589, June 2004.

Moeller, D.W., M.T. Ryan, L.C. Sun, and R.N. Cherry, *Impacts of Stable Element Intake on ^{14}C and ^{129}I Dose Estimate*, Health Physics, Vol. 89, p. 349–354, October 2005.

National Research Council of the National Academies (NAS), *Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident*, The National Academies Press, January 2004. Available at: https://www.nap.edu/read/10868/chapter/1

National Council on Radiation Protection and Measurements (NCRP), Report No. 159, *Risk to the Thyroid from Ionizing Radiation.* December 2008.

Otosaka, S., K. Schwehr, A. Kaplan, S.I., Roberts, K.A. Zhang, S. Xu, C., Li, H. P. et al. *Transformation and Transport Process of I-127 and I-129 Species in Groundwater at the F-Area at the Savannah River Site*, Science of the Total Environment, Vol. 409, p. 3857-3865. November 2011.

Schwehr, K.A., Otosaka, S., Merchel, S., Kaplan, D.I., Zhang, S., Xu, C. Li, H.-P., Ho, Y.-F., Yeager, C.M., Santschi, P.H., and ASTER Team. *Speciation of Iodine Isotopes Inside and Outside of a Contaminant Plume at the Savannah River Site*, Science of the Total Environment, Vol. 497-498, p.671–678. November 2014.

U.S. Department of Agriculture (USDA), *USDA, FDA and ODS-NIH Database for the Iodine Content of Common Foods*, June 2020. Available at: https://www.ars.usda.gov/arsuserfiles/80400535/data/iodine/iodine%20database_documentation_.pdf

U.S. Department of Energy (DOE), WSRC-RP-98-01352, Rev. 0, *Iodine-129 Dose in LLW Disposal Facility Performance Assessments*, December 1998. ADAMS Accession No. ML22040A159.

___, SRNL-STI-2009-00463, Rev. 0, *Groundwater Radioiodine: Prevalence, Biogeochemistry, and Potential Remedial Approaches*, September 2009. ADAMS Accession No. ML22040A170.

___, SRNL-STI-2012-00518, Rev. 0, *Radioiodine Geochemistry in the SRS Subsurface Environment,* May 2013. ADAMS Accession No. ML14196A201.

___, SRR-CWDA-2021-00047, Rev. 1, *Comment Response Matrix for the First Set of NRC Staff Requests for Additional Information on the Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site*, July 2021. ADAMS Accession No. ML21201A247.

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

___, Publication 26, *Recommendations of the International Commission on Radiological Protection,* Annals of the ICRP, Vol. 1(3), July 1977.

___, Publication 30, Part 1, *Limits for Intakes of Radionuclides by Workers*, Annals of the ICRP, Vol. 3(3-4), January 1979.

___, Publication 30, Part 2, *Limits for Intakes of Radionuclides by Workers*, Annals of the ICRP Vol. 4(3/4), 1980.

___, Publication 30, Part 3, *Limits for Intakes of Radionuclides by Workers*, Annals of the ICRP Vol. 6(2/3), 1981.

___, Publication 30, Part 4, *Limits for Intakes of Radionuclides by Workers: An Addendum*, Annals of the ICRP, Vol.19(4), 1988.

___, Publication 56, *Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 1*, Annals of the ICRP, Vol. 20 (2), 1989.

___, Publication 60, *Recommendations of the International Commission on Radiological Protection,* Annals of the ICRP, Vol. 21 (1–3). 1990.

___, Publication 71, *Age-dependent Doses to Members of the Public from Intake of Radionuclides - Part 4 Inhalation Dose Coefficients,* Annals of the ICRP, Vol. 25 (3-4). July-October 1995.

___, Publication 72, *Age-dependent Doses to the Members of the Public from Intake of Radionuclides - Part 5 Compilation of Ingestion and Inhalation Coefficients,* Annals of the ICRP, Vol. 26 (1). January 1996.

___, Publication 89, *Basic Anatomical and Physiological Data for Use in Radiological Protection: Reference Values,* Annals of the ICRP, Vol. 32 (3-4). September 2002.

___, Publication 100, *Human Alimentary Tract Model for Radiological Protection*, Annals of the ICRP, Vol. 36(1-2). 2006.

___, Publication 103, *The 2007 Recommendations of the International Commission on Radiological Protection*, Annals of the ICRP, Vol. 37 (2-4). 2007.

___, Publication 137, ICRP, *Occupational Intakes of Radionuclides: Part 3,* Annals of the ICRP Vol. 46 (3/4). 2017.

U.S. National Institutes of Health (NIH), Office of Dietary Supplements, *Iodine Fact Sheet for Health Professionals*, March 2021. Available at: https://ods.od.nih.gov/factsheets/Iodine-HealthProfessional/#en10

Zvonova, I.A. Dietary Intake of Stable I and Some Aspects of Radioiodine Dosimetry, Health Physics, Vol. 57, p.471–475. 1989.