Technical Review: Inadvertent Intrusion Analysis 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 is to document the NRC staff review of the U.S. Department of Energy (DOE) analyses of the projected dose to an individual who inadvertently intrudes on the Saltstone Disposal Facility (SDF) at the Savannah River Site (SRS). The DOE included inadvertent intrusion analyses with the DOE 2020 Performance Assessment (PA) for the SDF. Under the Ronald W. Reagan National Defense Authorization Act for Fiscal Year (FY) 2005 (NDAA), the NRC staff performed this review to support a future decision about whether the DOE has demonstrated that radioactive waste disposal at the SDF complies with the performance objective [PO] entitled "Protection of Individuals from Inadvertent Intrusion" in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 61, Subpart C (i.e., 10 CFR 61.42).

The NRC staff's current plan for NDAA-monitoring at the SDF (referred to as the NRC SDF Monitoring Plan in this Technical Review Report (TRR)) is available in the NRC's Agencywide Documents Access and Management System (ADAMS) under Accession No. ML13100A113. The NRC SDF Monitoring Plan describes how the NRC staff, in coordination with the NDAA-Covered State of South Carolina for the SRS, will assess the DOE compliance with the POs under 10 CFR Part 61. For 10 CFR 61.42, the NRC Monitoring Plan indicates that the NRC staff will assess compliance by comparing the projected dose to an inadvertent intruder to a 5 mSv/yr (500 mrem/yr) Total Effective Dose Equivalent limit, in accordance with the guidance in NUREG-1854, "NRC Staff Guidance for Activities Related to U.S. DOE Waste Determinations - Draft Report for Interim Use". This Technical Review Report (TRR) also provides the technical bases for NRC staff recommended modifications to the NRC Monitoring Plan. In this TRR, the staff numbered those recommendations (e.g., INTA-01, INTA-02) to facilitate cross-referencing the future revised NRC SDF Monitoring Plan.

The NRC SDF Monitoring Plan does not include a specific monitoring area (MA) for inadvertent intrusion. Instead, the NRC SDF Monitoring Plan identifies applicable POs for each monitoring factor (MF) as pertaining to 10 CFR 61.42. Most of the monitoring factors in the NRC SDF Monitoring Plan apply to both 10 CFR 61.41 (Protection of the General Population from Releases of Radioactivity) and 10 CFR 61.42. Therefore, this TRR supports NDAA-monitoring under most of the monitoring factors in the NRC SDF Monitoring Plan. In this TRR, the NRC staff also recommends new monitoring factors that pertain only to inadvertent intrusion. The basis for all the NRC staff recommended changes to the NRC SDF Monitoring Plan appear in Section 4.0, "NRC Staff Evaluation." This TRR also lists each recommendation in Section 7.0, "Conclusions."

2.0 Background

This is the first NRC TRR on inadvertent intrusion into the SDF. The NRC staff previously addressed inadvertent intrusion into the SDF in the following documents:

- 2005 NRC SDF Technical Evaluation Report (TER) (ML053010225);
- 2005 NRC Request for Additional Information (RAI) on the 2005 DOE Draft SDF Waste Determination (ML051440589);
- 2007 NRC SDF Monitoring Plan (ML070730363);
- 2012 NRC SDF TER (ML121170309); and
- 2013 NRC SDF Monitoring Plan (ML13100A076).

The 2012 NRC TER for the SDF (referred to as the 2012 TER in this TRR) concluded that the NRC had reasonable assurance that the DOE disposal actions at the SDF would meet the PO for Protection of Individuals from Inadvertent Intrusion (i.e., 10 CFR 61.42). The NRC staff made changes to the NRC SDF Monitoring Plan based on the analysis documented in that TER. After the NRC issued the NRC SDF Monitoring Plan, the NRC staff reviewed both the DOE FY 2013 and FY 2014 SDF Special Analysis Documents (ML14002A069 and ML15097A366). However, the NRC did not make conclusions about inadvertent intrusion at the SDF based on those two DOE documents. Therefore, the 2012 TER and NRC SDF Monitoring Plan represent the NRC staff's most recent review of inadvertent intrusion at the SDF.

3.0 Inadvertent Intrusion Analysis for the DOE 2020 PA

3.1 Overview

The DOE expects that the U.S. Federal Government will maintain control of the SDF in perpetuity, which would preclude inadvertent intrusion at the SDF. However, in accordance with both DOE Manual 435.1-1 and 10 CFR 61.42, the DOE assessed the potential dose to an individual who inadvertently intrudes onto the SDF (referred to as an "inadvertent intruder" in this TRR). The DOE selected intrusion exposure scenarios based on site (i.e., SRS), facility (i.e., SDF), and SDF waste characteristics. The DOE expected that the most likely type of intrusion into the SDF would be for an individual to drill a water well into soil near a disposal structure. The DOE evaluated both acute exposures to an individual drilling the well and chronic exposures to a person who lives on the site after contaminated drill cuttings have been brought to the surface. The DOE used the projected dose to a chronically exposed individual as the basis for the 10 CFR 61.42 PO compliance demonstration because the DOE analyses resulted in larger projected doses for a chronically exposed individual than an acutely exposed individual.

In addition to projecting doses due to exposure to soil drill cuttings, the DOE projected acute and chronic doses if an individual drilled through a disposal structure and brought saltstone grout to the land surface in the drill cuttings. The 2020 SDF PA indicates that the DOE expects that it would be unlikely for an individual to inadvertently drill into saltstone because the saltstone is protected by engineered barriers, including the erosion barrier and steel-reinforced concrete disposal structure roofs, which are very different from typical soil near the SDF.

Consequently, the DOE expects that an individual who began drilling into a disposal structure would recognize that the barriers were significantly more difficult to drill into than the natural local subsurface material and would move the drilling location. For that reason, the DOE characterized the evaluation of drilling into saltstone grout as an alternative analysis. Section 3.3 in this TRR describes other potential types of intrusion (i.e., mining, building a home) that the DOE considered and excluded from detailed analysis.

A hypothetical individual drilling into soil near a disposal structure or drilling directly into a disposal structure represent two different ways an inadvertent intruder could bring contaminated material to the surface. For each method of intrusion, an individual would have different exposure pathways for acute and chronic exposures. This TRR uses the term “soil-drilling scenarios” to refer to acute and chronic intrusion exposure scenarios resulting from an individual drilling into contaminated soil near a disposal structure. Similarly, this TRR uses the term “grout-drilling scenarios” to refer to acute and chronic intrusion exposure scenarios resulting from an individual drilling into a disposal structure.

The DOE modeled different intrusion times for the soil-drilling and grout-drilling scenarios. Although the DOE plans to maintain control of SRS in perpetuity, in the deterministic analysis the DOE assumed an individual would drill a well into soil near a disposal structure 100 years after closure. For the grout-drilling intrusion scenario, the DOE assumed that an individual would only drill into saltstone grout after a disposal structure roof was completely degraded (see Section 3.2 in this TRR).

The DOE based the intrusion analyses on many of the same models and calculations the DOE used to project a dose to an offsite member of the public (i.e., an individual living 100 m [330 ft] from the SDF boundary) for the purpose of demonstrating compliance with the 10 CFR 61.41 PO, with certain adjustments. For example, for chronic exposures, the DOE used the same Dose and Exposure Pathways Model (referred to as the Dose Model in this TRR) in the intrusion analysis that the DOE used to project a dose for an offsite member of the public, with adjustments to account for the different intrusion exposure scenarios (see Section 3.5 in this TRR). Similarly, the DOE used the same Aquifer Transport Model to determine groundwater radionuclide concentrations for a chronically exposed inadvertent intruder and offsite member of the public, with adjustments to account for the different receptor locations. The NRC staff reviewed the Aquifer Transport Model in a TRR on Far-Field Flow and Transport (ML22131A062). Therefore, this TRR focuses on the following areas:

- models and parameters specifically applicable to intrusion (e.g., volume of drill cuttings);

- conceptual model differences between intrusion and projections of an offsite member of the public and whether those differences are reflected in the mathematical models; and

- aspects of the models the NRC staff found to have insufficient technical bases in the review of the analysis for an offsite member of the public that also apply to the model for an inadvertent intruder.

The DOE modeled three cases as part of its Central Scenario intrusion analyses: 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 POs. The DOE described the Pessimistic Case as based on parameter values that are biased toward increasing dose results and maximizing defensibility. Throughout this TRR, the NRC staff uses the terms Realistic, Compliance, and Pessimistic 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.

3.2 Intrusion Barriers

The DOE expects several elements of the Closure Cap and engineered features of the disposal structures will limit the probability and extent of intrusion. The DOE plans to cover the disposal structures with two engineered closure caps. A cap on the southern part of the SDF will cover Saltstone Disposal Structure[1] (SDS) 1 and SDS 4. A cap on the northern part of the SDF will cover the six 150-foot disposal structures (i.e., SDS 2A, SDS 2B, SDS 3A, SDS 3B, SDS 5A, SDS 5B) and seven 375-foot disposal structures (i.e., SDS 6, SDS 7, SDS 8, SDS 9, SDS 10, SDS 11, SDS 12). Although the southern and northern caps are separate features, in this TRR the NRC staff uses the simplification the DOE used in the 2020 SDF PA by referring to both caps collectively as the “Closure Cap.” The NRC staff described the Closure Cap in further detail in a separate TRR on percolation through and potential erosion near the Closure Cap (ML23017A083).

The Closure Cap includes a layer of riprap, which the DOE calls the “erosion barrier.” The DOE designed the erosion barriers to maintain no less than 3.3 meters (m) (10 feet [ft]) of clean material above the disposal structures. The DOE expects the depth of clean material above the SDF would preclude certain types of intrusion, such as disrupting waste to excavate land for the construction of a dwelling. In addition, the DOE expects the layer of riprap to preclude burrowing animals from the SDF. The DOE also expects that the riprap and High-Density Polyethylene (HDPE) used in the Closure Cap would present a recognizable man-made barrier to an inadvertent intruder and discourage intrusion.

As indicated in Section 3.1 in this TRR, the DOE also assumed that an individual could not intrude into a disposal structure until the disposal structure roof completed degraded. The DOE used the Conservative Estimate of roof concrete degradation times in Table 1, below, as the earliest possible times for intrusion into a disposal structure.

Table 1. Modeled Times of Intrusion (from Section 6.2.1.2 in DOE 2020 SDF PA)

Disposal Structures	Years After Site Closure (years)
SDS 1	638
SDS 4	518
SDS 2A, SDS 2B, SDS 3A, SDS 3B, SDS 5A, SDS 5B	914
SDS 6, SDS 7, SDS 8, SDS 9, SDS 10, SDS 11, SDS 12	1,371

3.3 Exposure Scenarios

In the 2020 SDF PA, the DOE indicated that the only plausible intrusion event onsite would be the installation of a water well. The DOE considered the potential for intrusion into waste during mining activity and excavation for a home and determined that those two scenarios were implausible. The DOE screened in a Feature, Event, or Process (FEP) for the impacts of leaving

[1] The DOE uses the term Saltstone Disposal Unit (SDU) instead of the NRC term SDS.

transfer lines onsite (i.e., FEP 3.3.01) and determined that the analysis could be deferred until site closure plans were further developed. The DOE also considered the potential for an individual to drill directly into a disposal structure. Although the DOE considered that possibility to be implausible, the DOE included that analysis in the 2020 SDF PA to provide risk insights.

The DOE determined that the potential for mining is minimal because of limited economically viable resources onsite. To evaluate the potential for mining, the DOE first determined that sand, gravel, clay, carbonate, and phosphate are the only economically viable deposits expected to occur in the Atlantic Coastal Plain, where the SRS is located. The DOE evaluated the potential for each type of deposit at SRS and determined that the only one that might be viable at SRS would be sand from borrow pits. The DOE did not provide a basis for excluding intrusion by excavating a borrow pit for sand from the intrusion analysis.

The DOE determined that it would be unlikely for an individual to disrupt a disposal structure by excavating to build a home because the erosion barrier would maintain at least 3.3 m (10 ft) of clean material above each of the disposal structures. In addition, the DOE determined that the steel-reinforced concrete disposal structure roofs would discourage an individual from excavating further until it becomes completely hydraulically degraded. The DOE evaluated the effects of potential excavation of the top of the Closure Cap with a sensitivity analysis the DOE referred to as the “Soil-Only Closure Cap Scenario.” That scenario resulted in a peak projected dose within 10,000 years of 0.12 mSv/yr (12 mrem/yr) for an offsite member of the public.

The DOE projected acute exposure to an individual who installs a water well onsite and chronic exposure to an individual who lives on site after a well is installed. For acute exposure, the DOE considered exposure to drill cuttings for 20 hours (h) while an individual drills a well. For chronic exposure, the DOE considered exposure to drill cuttings after a well driller spreads the cuttings on the land surface. The DOE assumed that contaminated drill cuttings would be a source for both acute and chronic exposures. In addition, the DOE assumed that a chronically exposed individual would be exposed to contaminated water from the well for agricultural and domestic uses.

For wells drilled into soil (rather than saltstone), the DOE considered two types of potential well locations: (1) points 1 m (3.3 ft) from the SDF (called the “1-m boundary” location in this TRR) and (2) seven locations within the SDF boundary that the DOE expected to have higher radionuclide concentrations, which the DOE called “intruder well” locations. The DOE chose the 1-m boundary well locations based on the locations the PORFLOW Aquifer Transport Model projected to have the highest radionuclide concentrations at any depth and at any time within 20,000 years of site closure. Section 3.4.1 in this TRR provides additional information about the hypothetical well locations.

To facilitate comparison of the dose contributions from exposure to well water and drill cuttings, the DOE evaluated scenarios with groundwater use only (i.e., no drill cuttings) in addition to scenarios that included drill cuttings. Therefore, in total, the DOE considered six types of intrusion scenarios:

- Acute exposure of a well driller to:
    - Soil drill cuttings
    - Saltstone drill cuttings

- Chronic exposure of a resident to:
    - Groundwater a 1-m well (no drill cuttings)

- Soil drill cuttings and groundwater at a 1-m well
- Saltstone grout drill cuttings and groundwater at a 1-m well
- Soil drill cuttings and groundwater from each of seven intruder well locations

3.4 Source Term

The DOE based source terms for intrusion scenarios on SDF inventories, radionuclide concentrations in groundwater, and assumptions about drill cutting volumes. To determine radionuclide concentrations in groundwater, the DOE used the same Aquifer Transport Model that the DOE used to project groundwater concentrations for an offsite member of the public, using different well locations. The NRC staff described the Aquifer Transport Model in another TRR (ML22131A062). Similarly, the NRC staff described the development of the SDF inventory in a separate TRR (ML21202A201). Therefore, this section describes how the DOE used those inputs with assumptions about drill cutting volumes to develop source terms for intrusion into soil or grout.

3.4.1 Water Concentrations and Well Locations

For soil-drilling scenarios, modeled radionuclide concentrations in groundwater affected both acute and chronic exposures. Although acute exposures did not include groundwater use, the DOE used radionuclide concentrations in groundwater to model radionuclide concentrations in soil drill cuttings at the well locations. For chronic intrusion scenarios, radionuclide concentrations in groundwater affected the projected dose both through the effect on projected radionuclide concentrations in soil and through water-dependent pathways.

The DOE projected radionuclide concentrations in the groundwater with the Aquifer Flow Model and Aquifer Transport Model. As described in Section 3.7.5 of this TRR, the DOE does not expect that intrusion into an SDF would significantly affect groundwater contamination. Therefore, the DOE used projected radionuclide concentrations from the Aquifer Transport Model without making changes to account for the effects of intrusion through the Closure Cap or a disposal structure.

The main difference between the groundwater radionuclide concentrations the DOE used for an inadvertent intruder and a member of the public was the modeled well locations. For a member of the public, the DOE modeled the radionuclide concentration at locations 100 m (328 ft) from the SDF boundary. For an inadvertent intruder, the DOE selected the location with the greatest radionuclide concentrations along the 1-m boundary in addition to seven locations within the boundary of the SDF that the DOE labeled as Inadvertent Human Intruder (IHI) wells (see Figure 1, below). The DOE assessed the point of maximum radionuclide concentration along the 1-m boundary each year, so that the location of the well always reflected the point of maximum concentration. In addition, the DOE chose the maximum concentration of each radionuclide irrespective of depth. Table 2 in this TRR provides the DOE basis for each intruder well location. The DOE determined that the projected dose at the point of maximum radionuclide concentration along the 1-m boundary was greater than the projected dose at any of the seven intruder wells.

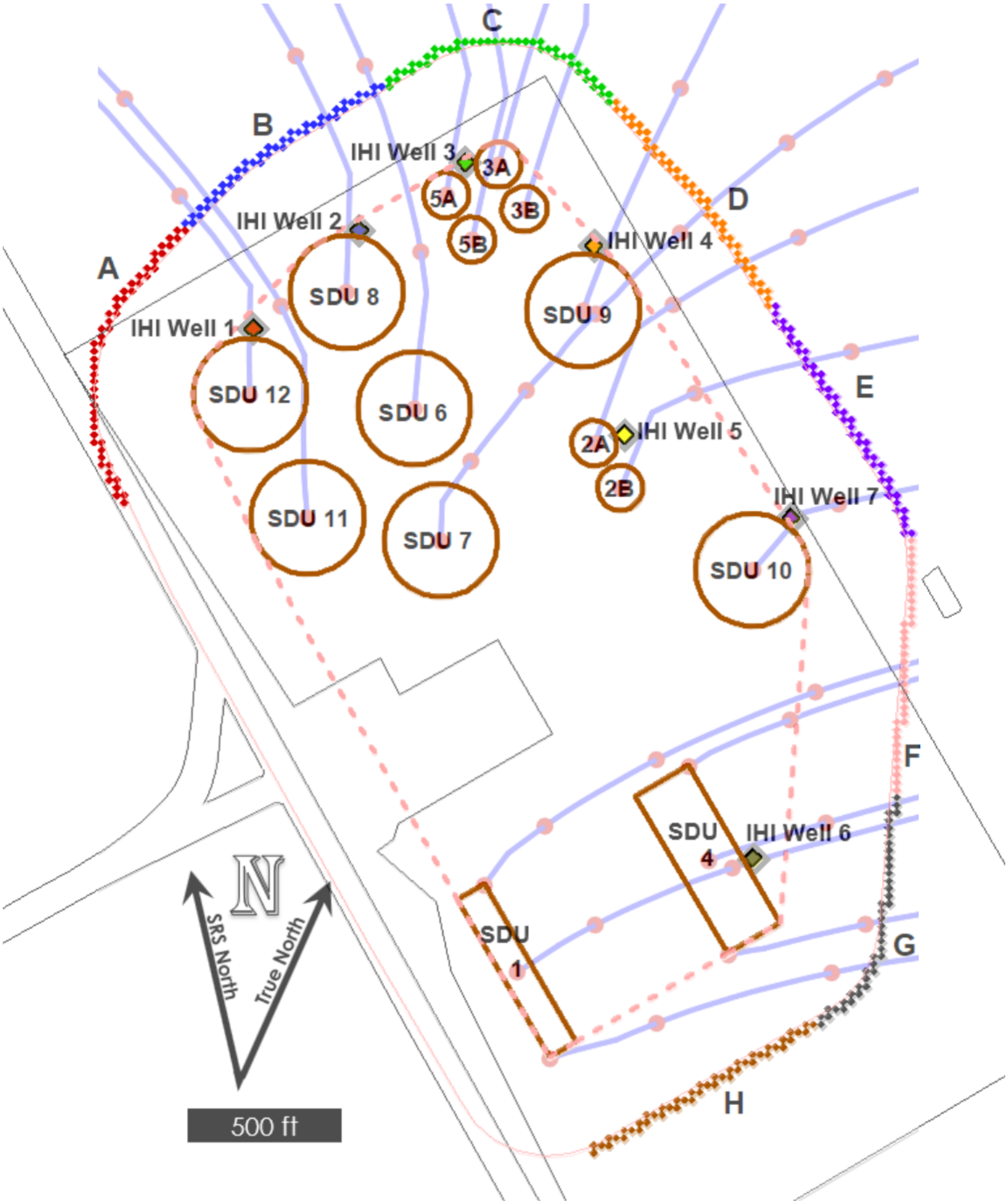

Figure 1. NRC staff overlay of DOE modeled intrusion well locations and DOE stream traces (adapted from Figures 4.4-115 and 6.1-1 in the 2020 SDF PA)

Table 2. DOE basis for intrusion well locations (adapted from Table 6.1-1 in the 2020 SDF PA)

Well Identifier	Location	Basis
IHI Well 1	Near SDS 12	Evaluate SDS 11 and SDS 12 plume overlap
IHI Well 2	Near SDS 8	Evaluate SDS 8 and SDS 6 plume overlap
IHI Well 3	Near SDS 5A	Evaluate plume from 150-foot disposal structures with SDS 6 plume overlap
IHI Well 4	Near SDS 9	Evaluate SDS 9 and SDS 7 plume overlap
IHI Well 5	Near SDS 2A	Evaluate SDS 2A and SDS 7 plume overlap
IHI Well 6	Near SDS 4	Evaluate SDS 1 and SDS 4 plume overlap
IHI Well 7	Near SDS 10	Evaluate plume from SDS 10

3.4.2 Soil Drill Cuttings

The DOE calculated radionuclide concentrations in soil based on groundwater radionuclide concentrations. Conceptually, the DOE chose to use Pessimistic Case groundwater concentrations for that calculation. However, the DOE calculated Pessimistic Case values only for iodine-129 (I-129), technetium-99 (Tc-99), and chlorine-36 (Cl-36). The DOE estimated the Pessimistic Case values for the remaining radionuclides by applying an adjustment factor to the Compliance Case concentrations calculated by the Aquifer Transport Model. In response to an NRC RAI question, the DOE indicated that it based the adjustment factor on the ratio of the calculated Pessimistic Case and Compliance Case values for I-129, Tc-99, and Cl-36 (SRR-CWDA-2021-00047, Rev. 1). The DOE calculated ratios of 7.79, 2.71, and 4.65 for I-129, Tc-99, and Cl-36, respectively, and chose the largest of the three values (i.e., 7.79) as the adjustment factor to estimate Pessimistic Case concentrations from Compliance Case concentrations for the radionuclides without Aquifer Transport Model Pessimistic Case concentrations[2].

The DOE originally assumed the soil concentrations would be equal to the concentration in an equivalent volume of water calculated with the PORFLOW-based Vadose Zone Transport Model and the Aquifer Transport Model without accounting for sorption to soil solids. In response to an NRC RAI question, the DOE calculated the concentration of radionuclides that would sorb onto soil using the Compliance Case soil sorption coefficients (SRR-CWDA-2021-00047, Rev. 1). In the drill cuttings inventory, the DOE included radionuclides both: (1) sorbed to soil solids and (2) dissolved in groundwater in soil pore space. Although the Vadose Zone Transport Model and the Aquifer Transport Models projected that radionuclide concentrations would vary with depth, the DOE assumed the whole well bore length would have radionuclide concentrations based on the peak groundwater concentrations at any depth. That decision would tend to overestimate the radionuclide concentrations in the drill cuttings because radionuclide concentrations at most depths would be less than the peak groundwater concentration at any depth.

To determine the inventory of radionuclides in the soil drill cuttings, the DOE multiplied the modeled volume of soil in the drill bore by the radionuclide concentrations in that volume. The DOE determined the total volume of the soil cuttings based on a well with a 0.203 m (8.0 inch

[2] This TRR describes the differences between the three Central Scenario Cases in Section 3.7.3. In brief, the differences that affect the soil-drilling scenario case are radionuclide transport properties in saltstone and disposal structure grout and radionuclide sorption coefficients in soil. For the soil-drilling scenario, the DOE only used the Pessimistic Case inventory (i.e., unlike for an offsite member of the public, for which the DOE Used the Realistic, Compliance, and Pessimistic inventories in the Central Scenario Cases).

[in]) diameter and a 30.5 m (100 ft) depth. The DOE modeled a well depth of 30.5 m (100 ft) because deeper wells would enter the Gordon Aquifer, which the DOE expects to have a lower radionuclide concentration. The DOE indicated that drilling into the Gordon Aquifer would tend to lower the projected dose because an individual using water from the well would be exposed to lower radionuclide concentrations than the individual would be if the DOE modeled drilling into the Upper Three Runs Aquifer. Because the DOE modeled the drill cuttings as having radionuclide concentrations based on the peak groundwater concentration along the well length, modeling a longer drill depth would not dilute the cuttings with cleaner soil because none of the drill cuttings are modeled with lower radionuclide concentrations than the peak. Table 3 provides the revised inventory that the DOE developed in the RAI response SRR-CWDA-2021-00047, Rev. 1).

Table 3. Soil drill cutting inventory (from Table IHI-3.5 in SRR-CWDA-2021-00047, Rev. 1)

Radionuclide	Curies (Ci)	Radionuclide	Curies (Ci)
Ac-227	2.32×10^{-14}	Pb-210	2.77×10^{-26}
Al-26	1.98×10^{-39}	Pt-193	2.96×10^{-37}
Am-241	1.70×10^{-39}	Pu-238	1.17×10^{-52}
Am-242m	1.04×10^{-57}	Pu-239	1.17×10^{-33}
Am-243	1.74×10^{-39}	Pu-240	3.13×10^{-34}
C-14	2.34×10^{-20}	Pu-241	2.47×10^{-39}
Cf-249	4.18×10^{-51}	Pu-242	1.41×10^{-34}
Cf-251	2.54×10^{-46}	Pu-244	5.96×10^{-37}
Cl-36	1.21×10^{-7}	Ra-226	4.64×10^{-26}
Cm-243	1.09×10^{-67}	Ra-228	6.01×10^{-42}
Cm-244	4.43×10^{-67}	Se-79	3.33×10^{-33}
Cm-245	1.59×10^{-39}	Sm-151	2.03×10^{-57}
Cm-247	1.09×10^{-39}	Sn-126	8.69×10^{-44}
Co-60	2.09×10^{-61}	Sr-90	2.22×10^{-37}
Cs-135	1.14×10^{-8}	Tc-99	2.51×10^{-5}
Cs-137	4.38×10^{-28}	Th-229	6.54×10^{-16}
Eu-152	1.33×10^{-71}	Th-230	1.47×10^{-35}
Eu-154	5.62×10^{-73}	Th-232	1.47×10^{-42}
H-3	6.27×10^{-45}	U-232	2.99×10^{-57}
I-129	3.74×10^{-7}	U-233	2.25×10^{-15}
K-40	2.07×10^{-8}	U-234	4.27×10^{-34}
Nb-93m	5.49×10^{-39}	U-235	4.69×10^{-36}
Nb-94	2.20×10^{-36}	U-236	4.49×10^{-36}
Ni-63	7.74×10^{-32}	U-238	3.96×10^{-36}
Np-237	1.52×10^{-13}	Zr-93	2.43×10^{-38}
Pa-231	7.21×10^{-15}		

3.4.3 Saltstone Grout Drill Cuttings

To model acute exposure to saltstone grout drill cuttings, the DOE used radionuclide concentrations in grout multiplied by the volume of saltstone drill cuttings. The DOE used the Realistic Case inventory developed for an offsite member of the public, which the NRC staff described in a TRR for saltstone inventory (ML23017A087). The 2020 SDF PA indicates that the DOE used the Realistic Case inventory instead of the Compliance Case inventory because the DOE expected that an individual would be unlikely to drill into saltstone grout.

The DOE used different volumes for soil and grout drill cuttings. In Section 6.2.1.2 of the 2020 SDF PA, the DOE assumed that drilling into a disposal structure would require a coring bit instead of a mud rotary drill, as the DOE assumed for drilling into soil. For that reason, the DOE assumed that the core would be removed essentially intact and discarded, and only an annular region corresponding to the thickness of the drill bit wall would be crushed and mixed with garden material. The DOE assumed the drill bit would have a 1.27-centimeter (cm) (0.5-in) wall thickness and would produce a 17.8-cm (7-in) diameter core. Therefore, the DOE assumed the cuttings would come from an annular area with a 20.3-cm (8.0-in) outer diameter and a 17.8-cm (7.0-in) inner diameter. The DOE assumed the heights of the contaminated cuttings corresponded to the full height of each type of disposal structure. Table 4 includes the resulting volumes of contaminated cuttings for grout-drilling scenarios for each type of disposal structure, as calculated by the NRC staff. It also includes the volume of the soil drill cuttings for comparison.

Table 4. Modeled drill cutting volumes

Cutting Source	Contaminated Cutting Depth (m)	Volume of Contaminated Cuttings[(a)] (m^3)
Soil	30.5	0.99
SDS 1	7.32	0.056
150-foot structures	6.55	0.050
SDS 4	7.54	0.057
375-foot structures	13.1	0.10

[(a)] The NRC staff calculated cutting volumes based on the cutting diameter and depth provided by the DOE in Section 4.4.8.2 of the 2020 SDF PA.

Table 5 shows the resulting grout drill cutting inventories based on the radionuclide concentrations associated with the Realistic Case radionuclide concentrations in saltstone grout and the drill cutting volumes in Table 4.

3.4.4 Concentrations in Garden Soil

For chronic exposures, the DOE calculated exposure to radionuclides in garden soil based on contamination from two sources: (1) radionuclide buildup in garden soil due to irrigation with contaminated groundwater and (2) mixing of drill cuttings (i.e., either soil or grout) with garden soil. Instead of adding sources of contamination to determine radionuclides concentrations in soil that reflected both sources, the DOE calculated soil concentrations separately. The DOE then calculated projected doses for each level of soil contamination and added the dose contributions from soils contaminated from each source. That method is mathematically equivalent to assuming the inventories add linearly.

To account for the contribution from buildup of radionuclides from contaminated irrigation water, the DOE used the same calculation of radionuclide buildup in soil that the DOE used for an offsite member of the public. The NRC staff reviewed the DOE representation of radionuclide buildup in a TRR on the Dose and Exposure Pathways model (ML23017A113). The only difference between the representation of buildup for an offsite member of the public and an inadvertent intruder was the radionuclide concentrations in the irrigation water, which were based on the applicable well locations (i.e., wells on the 100-m boundary for an offsite member of the public or wells 1-m from the SDF or on the SDF for an inadvertent intruder).

Table 5. Grout drill cutting inventories (from Table 6.2-2 in the 2020 SDF PA)

Radionuclide	SDS 1 (Ci)	SDS 4 (Ci)	SDS 3B (Ci)	SDS 7 – 12 (Ci)
Ac-227	3.34×10^{-12}	6.20×10^{-11}	6.21×10^{-12}	1.24×10^{-11}
Al-26	3.43×10^{-7}	6.33×10^{-7}	1.34×10^{-6}	2.69×10^{-6}
Am-241	3.02×10^{-9}	1.40×10^{-5}	7.83×10^{-4}	1.57×10^{-3}
Am-242m	8.12×10^{-11}	1.13×10^{-8}	3.80×10^{-7}	7.59×10^{-7}
Am-243	1.85×10^{-9}	3.36×10^{-7}	3.16×10^{-7}	6.31×10^{-7}
C-14	1.72×10^{-6}	4.22×10^{-6}	2.91×10^{-5}	5.82×10^{-5}
Cf-249	1.11×10^{-18}	1.73×10^{-7}	2.44×10^{-18}	4.88×10^{-18}
Cf-251	3.98×10^{-20}	5.95×10^{-8}	8.57×10^{-20}	1.71×10^{-19}
Cl-36	1.28×10^{-13}	9.70×10^{-9}	4.95×10^{-8}	9.90×10^{-8}
Cm-243	3.84×10^{-10}	3.42×10^{-9}	1.45×10^{-9}	2.90×10^{-9}
Cm-244	1.89×10^{-9}	1.01×10^{-5}	5.63×10^{-6}	1.13×10^{-5}
Cm-245	3.55×10^{-10}	5.05×10^{-7}	4.26×10^{-9}	8.52×10^{-9}
Cm-247	2.08×10^{-19}	6.90×10^{-8}	4.39×10^{-19}	8.78×10^{-19}
Co-60	4.60×10^{-11}	3.73×10^{-9}	4.22×10^{-7}	8.44×10^{-7}
Cs-135	6.48×10^{-8}	1.12×10^{-6}	6.67×10^{-8}	1.33×10^{-7}
Cs-137	5.33×10^{-6}	7.10×10^{-2}	1.22×10^{-2}	2.45×10^{-2}
Eu-152	7.60×10^{-10}	1.80×10^{-8}	4.40×10^{-7}	8.80×10^{-7}
Eu-154	1.48×10^{-10}	4.37×10^{-7}	4.06×10^{-6}	8.12×10^{-6}
H-3	6.04×10^{-6}	7.97×10^{-6}	1.71×10^{-4}	3.41×10^{-4}
I-129	2.63×10^{-7}	1.80×10^{-7}	8.42×10^{-7}	1.68×10^{-6}
K-40	1.28×10^{-13}	9.70×10^{-9}	4.95×10^{-8}	9.90×10^{-8}
Nb-93m	9.84×10^{-7}	1.25×10^{-3}	4.88×10^{-6}	9.76×10^{-6}
Nb-94	2.65×10^{-9}	5.79×10^{-8}	7.53×10^{-9}	1.51×10^{-8}
Ni-63	1.37×10^{-7}	1.78×10^{-6}	1.10×10^{-5}	2.19×10^{-5}
Np-237	5.16×10^{-9}	3.74×10^{-7}	6.36×10^{-7}	1.27×10^{-6}
Pa-231	5.33×10^{-12}	9.89×10^{-11}	1.60×10^{-11}	3.20×10^{-11}
Pb-210	5.52×10^{-13}	2.10×10^{-11}	1.27×10^{-12}	2.54×10^{-12}
Pt-193	1.65×10^{-6}	4.44×10^{-6}	3.81×10^{-6}	7.61×10^{-6}
Pu-238	8.09×10^{-9}	1.74×10^{-4}	7.98×10^{-3}	1.60×10^{-2}
Pu-239	1.87×10^{-8}	3.80×10^{-5}	4.94×10^{-4}	9.89×10^{-4}
Pu-240	1.76×10^{-8}	4.72×10^{-5}	1.03×10^{-4}	2.06×10^{-4}
Pu-241	1.08×10^{-8}	2.34×10^{-5}	9.38×10^{-4}	1.88×10^{-3}
Pu-242	2.05×10^{-9}	2.68×10^{-6}	1.67×10^{-7}	3.33×10^{-7}
Pu-244	1.33×10^{-11}	1.09×10^{-8}	7.70×10^{-10}	1.54×10^{-9}
Ra-226	1.25×10^{-12}	5.37×10^{-11}	3.56×10^{-12}	7.12×10^{-12}
Ra-228	1.01×10^{-11}	1.36×10^{-10}	1.44×10^{-8}	2.87×10^{-8}
Se-79	4.50×10^{-7}	6.33×10^{-6}	5.02×10^{-6}	1.00×10^{-5}
Sm-151	6.25×10^{-9}	1.10×10^{-5}	2.15×10^{-4}	4.31×10^{-4}
Sn-126	1.60×10^{-6}	1.44×10^{-6}	1.95×10^{-5}	3.90×10^{-5}
Sr-90	1.28×10^{-8}	9.75×10^{-4}	2.02×10^{-1}	4.04×10^{-1}
Tc-99	6.45×10^{-5}	4.12×10^{-4}	1.19×10^{-3}	2.37×10^{-3}
Th-229	6.98×10^{-10}	2.36×10^{-6}	2.88×10^{-9}	5.76×10^{-9}
Th-230	8.48×10^{-11}	4.10×10^{-9}	2.50×10^{-10}	5.01×10^{-10}
Th-232	1.01×10^{-11}	1.36×10^{-10}	1.44×10^{-8}	2.87×10^{-8}
U-232	7.06×10^{-10}	6.31×10^{-8}	1.98×10^{-9}	3.96×10^{-9}
U-233	1.02×10^{-7}	5.75×10^{-6}	6.45×10^{-7}	1.29×10^{-6}
U-234	1.30×10^{-7}	5.83×10^{-6}	1.07×10^{-6}	2.14×10^{-6}
U-235	3.29×10^{-9}	6.08×10^{-8}	2.61×10^{-8}	5.22×10^{-8}
U-236	8.50×10^{-9}	5.42×10^{-8}	5.84×10^{-8}	1.17×10^{-7}
U-238	1.41×10^{-8}	5.15×10^{-8}	8.47×10^{-7}	1.69×10^{-6}
Zr-93	1.01×10^{-6}	5.29×10^{-6}	4.95×10^{-6}	9.90×10^{-6}

For contamination from mixing with drill cuttings, the DOE used the inventory in either the soil or saltstone drill cuttings, depending on the scenario, and averaged those inventories over the volume of garden soil. To calculate the modeled volume of garden soil drill cuttings would be mixed into, the DOE multiplied the garden area by a mixing depth the DOE referred to as the “till depth” (i.e., 15 cm [6 in]). That is, the DOE assumed drill cuttings would be mixed into the top 15 cm [6 in] of the garden soil. The NRC staff used the term “till depth” in this TRR for consistency with the DOE terminology in the 2020 SDF PA. The DOE used the following equation (Equation 4.4-212 in the 2020 SDF PA) to average radionuclides over the volume of garden soil:

$$C_{IHIC,g} = \frac{Act_{max}}{A_{garden} \cdot d_{till}} \qquad \text{Eqn. 1}$$

where
$C_{IHIC,g}$ is the concentration of a radionuclide in the garden due to mixing with drill cuttings
A_{max} is the total activity for an individual radionuclide in the drill cuttings
A_{garden} is the garden area and
d_{till} is the tilling depth

For the deterministic calculation, the DOE used a 0.15 m (6.0 in) tilling depth and a 100 m^2 (1080 ft^2) garden area. The NRC staff reviewed the garden area in a TRR on the DOE Dose and Exposure Pathways Model (ML23017A113). For an offsite member of the public, increasing the modeled garden area increased the projected dose because the DOE calculated the fraction of local produce consumed based, in part, on the garden area. However, for a chronically exposed inadvertent intruder, decreasing the modeled garden area could increase the projected dose by increasing the modeled radionuclide concentrations in garden soil (i.e., per Equation 1).

In the 2020 SDF PA, the DOE used 100 m^2 as both the deterministic value for the garden area and as the lower limit for the probabilistic distribution of garden areas for both a member of the public and a chronically exposed inadvertent intruder. In response to an NRC RAI question, the DOE indicated that smaller garden areas would not be reasonable (SRR-CWDA-2021-00047, Rev. 1). The DOE based that determination on the volume of soil drill cuttings (i.e., 0.99 m^3), a till depth of 0.15 m, and an assumed loading of 20 percent drill cuttings in garden soil. The DOE calculated a minimum contaminated garden size of 33 m^2 as follows:

$$garden\ area = \frac{cuttings\ volume}{till\ depth \cdot dilution\ factor} = \frac{0.99\ m^3}{0.15\ m \cdot 0.2} = 33\ m^2 \qquad \text{Eqn. 2}$$

The DOE also listed additional considerations that would suggest the garden area would be greater than that minimum value. That DOE response did not address the smaller modeled garden area that would result if the DOE applied Equation 2 to the saltstone drill cuttings volumes (i.e., see Table 4 in this TRR).

3.5 Exposure Pathways

The DOE modeled different exposure pathways for acute and chronic exposures. In general, the DOE modeled the same exposure scenarios for a chronically exposed inadvertent intruder and an offsite member of the public, with slight differences in implementation. The DOE assumed an acutely exposed inadvertent intruder would experience a much smaller set of exposure pathway because of their limited time and activities onsite. The NRC reviewed the exposure pathways the DOE modeled for an offsite member of the public in a separate TRR on the DOE Dose and

Exposure Pathways Model (ML22076A128). Therefore, this TRR focuses on the following areas:

- differences between the DOE modeled exposure pathways for a member of the public and an inadvertent intruder; and

- modeled exposure pathways that the NRC staff found to have insufficient technical bases that also apply to the model for an inadvertent intruder

For each exposure pathway, the DOE calculated one or more Effective Dose Factors (EDFs) to convert the radionuclide concentration in a contaminated medium to the dose contribution from that medium through a specific exposure route. For example, the Dose Model includes an EDF for inhalation of water while swimming, which the Dose Model multiplies by the radionuclide concentrations in stream water to yield the dose contribution from inhaled water while swimming. Similarly, the Dose Model includes an EDF for acute direct exposure to saltstone in drill cuttings, which can be multiplied by the radionuclide concentrations in saltstone to yield the dose contribution from direct exposure for an individual who drills into a disposal structure. Because the DOE modeled most of the same exposure pathways for the chronically exposed intruder and a member of the public, the Dose Model uses some of the same EDFs in the dose projections for those two receptors. Subsequent sections in this TRR refer to the EDFs to compare the dose calculations for an inadvertent intruder to the dose calculations for an offsite member of the public.

3.5.1 Acute Exposure Pathways

The DOE assumed acute exposure would include the following exposure pathways:

- direct exposure to drill cuttings

- inhalation of suspended particles

- incidental ingestion of drill cuttings

For each pathway, the DOE assumed exposure would occur during well installation, which the DOE assumed would occur for 20 h based on DOE judgment of the time required for well installation.

For direct exposure, the DOE did not specify an assumed distance between the individual and the drill cuttings. However, to calculate the dose from direct exposure, the DOE used Dose Conversion Factors (DCFs) for direct exposure for an individual standing on volumetrically exposed soil (i.e., approximately 1 m (3.3 ft) distance from the ground to the center of the individual).

For inhalation of suspended particles while drilling, the DOE assumed a mass loading of 0.1 milligram (mg) per cubic meter of air. The DOE based that value on 30 measurements of soil loading in air in a “non-urban” location (UCRL-76419). The reference did not indicate the measurements represented soil-disturbing activities (e.g., gardening, well drilling). The DOE assumed all the particles were respirable. The DOE based the volume of air inhaled on an annual average inhalation rate of 8,000 m^3 and assumed 20 h of exposure.

For incidental ingestion of drill cuttings, the DOE assumed a well driller ingested drill cuttings at the same annual average rate of that the DOE used for incidental soil ingestion for a member of the public (i.e., 1.06 kilograms/year (kg/yr)). The DOE calculated the ingestion of drill cuttings by multiplying the annual average soil ingestion rate by the fraction of the year a well driller spent onsite (i.e., 20 h/8,760 h = 0.0023 (unitless)).

3.5.2 Chronic Exposure Pathways

The DOE considered the following chronic exposure pathways for an inadvertent intruder:

- direct radiation from
    - soil while gardening
    - groundwater while showering
    - stream water while swimming, boating, and fishing

- inhalation of
    - suspended soil while gardening[3]
    - suspended groundwater while showering
    - suspended groundwater while irrigating crops
    - suspended stream water while swimming

- ingestion of
    - groundwater used as drinking water
    - garden soil while in garden (incidental ingestion)
    - produce grown in contaminated garden soil
    - animal products (i.e., milk, meat, poultry, eggs) from animals that drink contaminated groundwater and eat feed grown in contaminated garden soil
    - fish from a contaminated stream

The DOE modeled most of those exposure pathways in the same way that the DOE modeled direct exposure, inhalation, and ingestion exposures for an offsite member of the public. The remainder of this subsection addresses the main differences in exposure pathway modeling for a chronically exposed inadvertent intruder and an offsite member of the public.

Unlike the dose calculation for a member of the public (see ML22076A128), the DOE did not model exposures from domestic or agricultural use of stream water for an inadvertent intruder because the DOE defined an inadvertent intruder as using groundwater for those purposes. However, the DOE did include the projected dose from swimming, boating, and fishing in stream water in the dose projection for the chronically exposed inadvertent intruder.

The DOE considered two sources of contamination of garden soil for a chronically exposed inadvertent intruder. First, the DOE modeled garden contamination by irrigation with contaminated water, as DOE did for an offsite member of the public. Second, the DOE modeled contamination from irrigation and from mixing of drill cuttings with garden soil.

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[3] In Section 4.4.8.2.4 of the 2020 SDF PA, the DOE indicated that the DOE intended to model inhalation of suspended soil while gardening. However, the Dose Model implemented different time fractions for inhalation of suspended soil depending on the contamination source. The DOE used the element “Fraction In Garden,” for inhalation of soil contaminated by irrigation with contaminated water and the element “Fraction Drilling” for the dose contribution from inhaling suspended soil contaminated by mixing with drill cuttings. Section 4.5.2 in this TRR addresses the difference and its risk significance.

For inhalation, the main difference between exposure pathways for an offsite member of the public and a chronically exposed inadvertent intruder was the representation of exposures from volatilized radionuclides (i.e., in contrast to suspended radionuclides). For suspended radionuclides, the DOE used the same Dose Model inhalation pathways for both receptors, with minor differences in implementation (see Section 4.5.2 in this TRR). In contrast, for radionuclides volatilized from saltstone, the DOE only calculated exposures for an offsite member of the public.

In the 2020 SDF PA, the DOE indicated that it did not calculate the projected dose to a chronically exposed inadvertent intruder from volatilized radionuclides because the DOE expected the dose to be negligible. The DOE indicated that it based that determination on the negligible projected dose to an offsite member of the public from volatilized radionuclides (i.e., 5.2×10^{-11} mSv/yr [5.2×10^{-9} mrem/yr] for radionuclides other than Radon-222 (Rn-222) with a Rn-222 peak flux of 2.7×10^{-5} becquerel/(m^2·second [s]) second [7.4×10^{-4} picoCuries/(m^2·s)]). The DOE basis did not address factors that could cause the dose to an inadvertent intruder to be greater than the dose to an offsite member of the public. For example, the DOE did not address how the concentration of radionuclides in a home built above a disposal structure would compare to the concentration of radionuclides that volatilize from saltstone and disperse to the 100-m (328-ft) boundary.

3.6 Deterministic Dose Projections

In general, the DOE projected greater doses to an individual who is chronically exposed to drill cuttings while living onsite than to an individual who experiences acute exposure to drill cuttings while drilling near or through a disposal structure. This section addresses the six exposure scenarios listed in Section 3.3 above.

3.6.1 Doses from Acute Exposure

The DOE projected doses for the acute exposure of an individual who drills a well near a disposal structure (i.e., “soil drill cuttings”) or through a disposal structure (i.e., “saltstone drill cuttings”) are provided below.

Soil Drill Cuttings

As described in Section 3.4.2 in this TRR, the DOE modified the source term for soil drill cuttings to account for radionuclide sorption to soil in response to an NRC RAI question. As shown in Figure 2, the DOE response (SRR-CWDA-2021-00047, Rev. 1) indicated slightly greater projected doses than the original analysis in the 2020 SDF PA. However, the projected doses were well below the 5 mSv/yr (500 mrem/yr) dose constraint the NRC uses to evaluate compliance with the 10 CFR 61.42 PO for an inadvertent intruder (see Section 1.0 in this TRR for additional information on the 5 mSv/yr [500 mrem/yr]) dose constraint). The DOE response did not provide dominant radionuclides or pathways for the revised dose projection. However, the model files the DOE provided with the response indicated that almost all of the projected dose could be attributed to incidental ingestion of drill cuttings. The DOE model output also showed that I-129 made the largest contribution to the projected dose, followed by Tc-99. No other radionuclides contributed significantly to the projected dose from acute exposure for an individual drilling near a disposal structure.

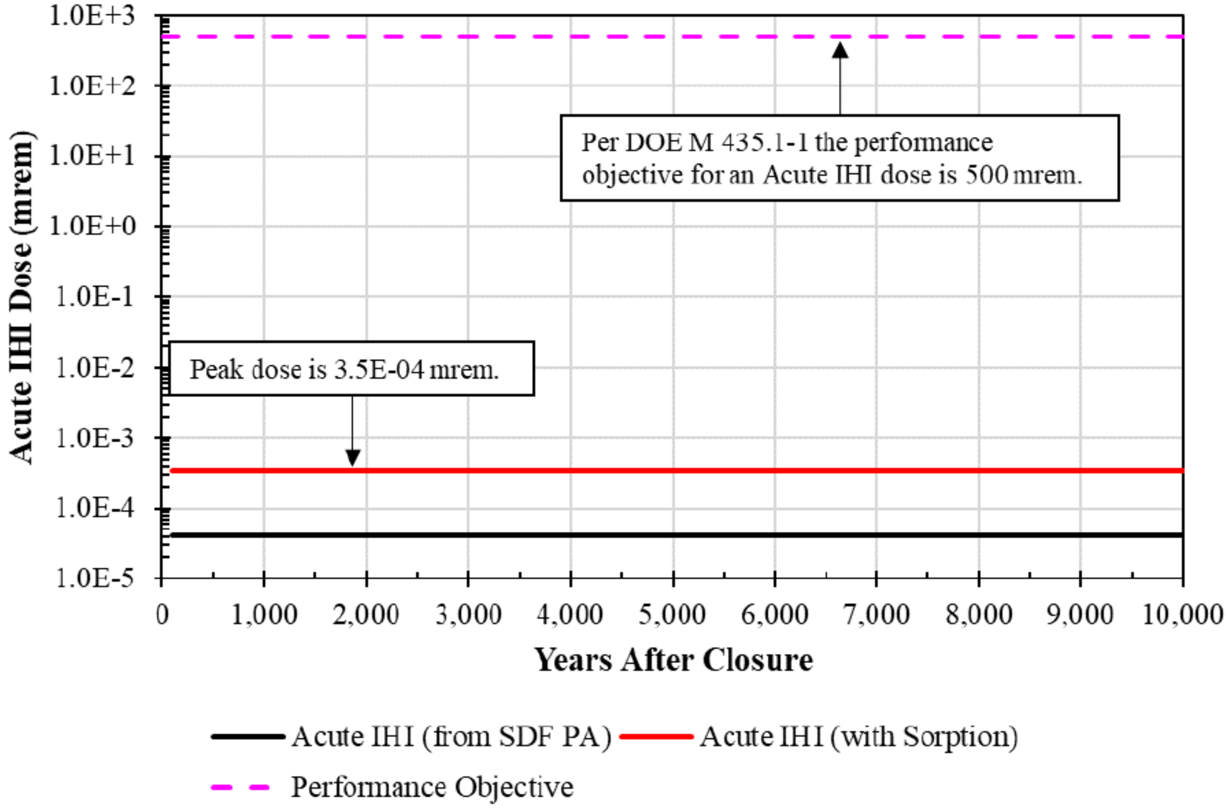

Figure 2. Projected dose from acute exposure for an inadvertent intruder (Figure IHI-3.1 in SRR-CWDA-2021-00047, Rev. 1)

Saltstone Drill Cuttings

The DOE projected larger doses from acute exposure to drill cuttings for an individual who drills through a disposal structure (see Figure 3, below). The DOE projected the greatest doses for an individual who drills through a 375-foot disposal structure, followed by a 150-foot disposal structure, SDS 4, and SDS 1. All the doses that the DOE projected were significantly less than the 5 mSv/yr (500 mrem/yr) dose constraint the NRC uses to evaluate compliance with 10 CFR 61.42. As for acute exposure to drilling into soil near a disposal structure, the DOE projected that the primary exposure pathway would be incidental ingestion of suspended drill cuttings. For all the disposal structures, the DOE projected that the four radionuclides that would make the greatest contributions to the peak dose for acute exposure are plutonium-239 (Pu-239), tin-126 (Sn-126), Pu-240, and americium-241 (Am-241).

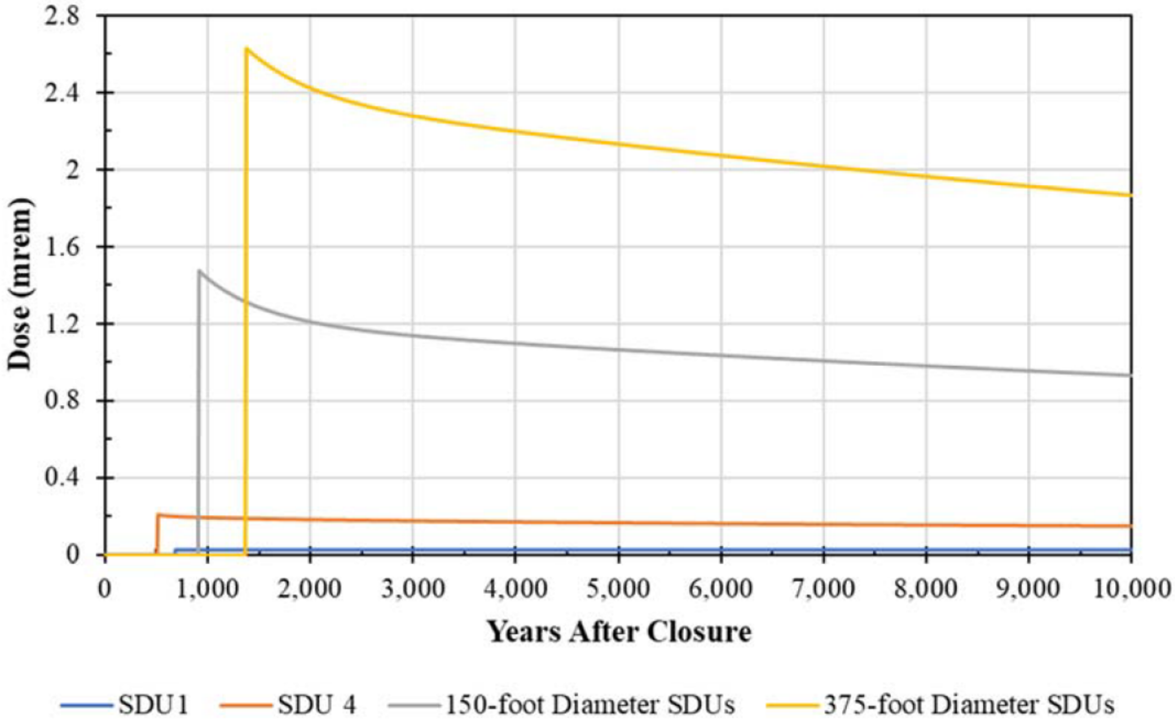

Figure 3. Projected dose from acute exposure for an individual who drills through a disposal structure (Figure 6.3-3 in the 2020 SDF PA)

3.6.2 Doses from Chronic Exposure

The DOE projected doses due to the chronic exposure of an individual who lives on the SDF after an individual drills a well near or through a disposal structure.

Soil Drill Cuttings

Figure 4, below, shows the projected dose to a chronically exposed individual in a soil-drilling scenario for both the original calculation in the 2020 SDF PA and the DOE revised inventory to account for sorption (SRR-CWDA-2021-00047, Rev. 1). As shown in Figure 4, the DOE RAI response provided slightly greater projected doses than the original analysis in the 2020 SDF PA. However, the projected doses were well below the 5 mSv/yr (500 mrem/yr) dose constraint the NRC uses to evaluate compliance with the 10 CFR 61.42 PO for an inadvertent intruder. Figure 4 also shows a 1 mSv/yr (100 mrem/yr) performance objective for the first 100 years after SDF closure. That performance objective is based on DOE M 435.1 and does not reflect an NRC performance objective.

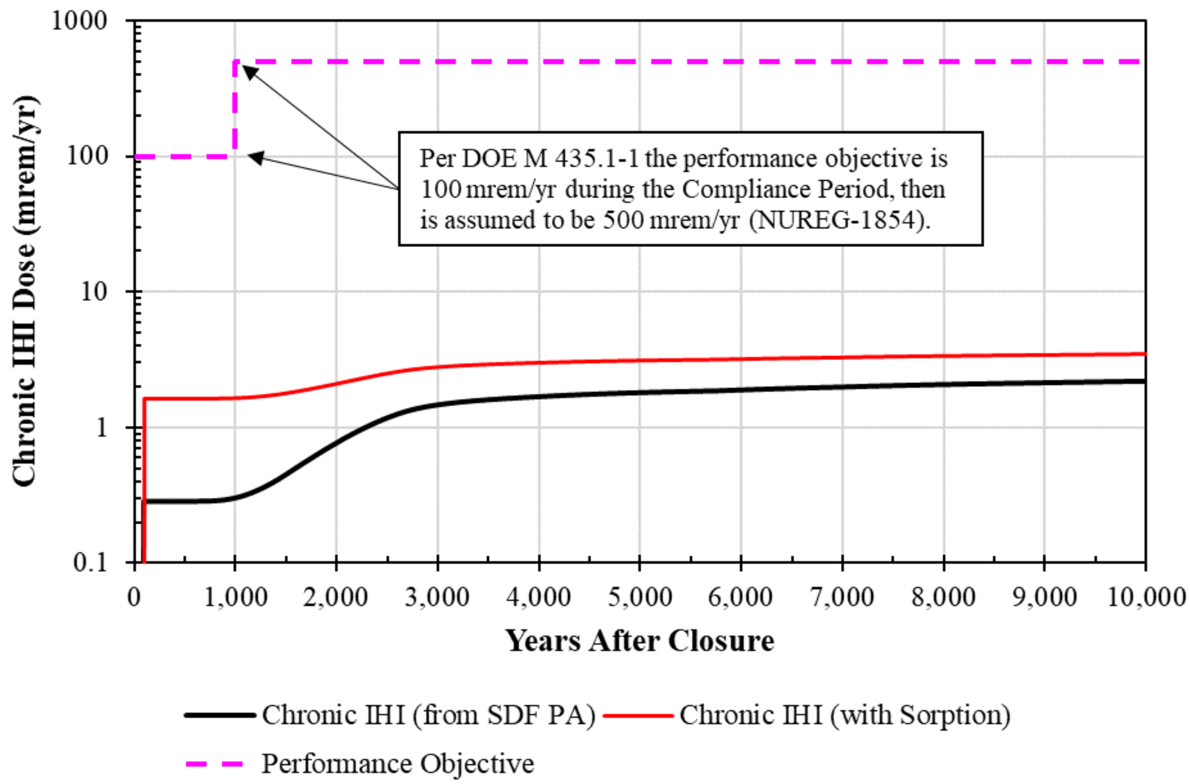

Figure 4. Projected dose from chronic exposure to soil drill cuttings and contaminated groundwater at the SDF (Figure IHI-3.2 in SRR-CWDA-2021-00047, Rev. 1)

Although the DOE did not provide dominant radionuclides or pathways for the revised dose projection in the DOE response, the model files provided with the DOE response indicated that plant ingestion contributed most to the projected dose within 2,000 years of site closure, and water ingestion contributed most to the projected dose between 2,000 and 10,000 years after SDF closure. The DOE model output also showed that Tc-99 made the greatest contribution to the projected dose within 10,000 years of site closure (73 percent), followed by I-129 (28 percent). No other radionuclides contributed significantly to the projected dose from acute exposure for an individual drilling near a disposal structure.

Groundwater Only

To assess the relative contributions of exposure to radionuclides brought to the surface in groundwater as compared to radionuclides in drill cuttings, the DOE analyzed some scenarios using the groundwater concentrations at the 1-m (3.3-ft) well without any contribution from drill cuttings. Figure 5 below shows that the importance of the contribution from groundwater increases with time. Because the DOE conducted the "groundwater-only" analysis in the 2020 SDF PA (i.e., before revising the soil drill cuttings source term to account for sorption) the black line in Figure 5 corresponds to the original soil drill cuttings source term. As shown in Figure 4, above, the revised source term increased the projected peak dose within 10,000 years by approximately 50 percent. Based on that revision, the peak dose from groundwater alone would account for a little over half of the projected peak dose within 10,000 years for the chronically exposed inadvertent intruder in the soil-drilling scenario (i.e., 0.019 mSv/yr [1.9 mrem/yr] from groundwater, as shown in Figure 4, versus a revised total peak dose of approximately 0.032 mSv/yr [3.2 mrem/yr], as shown in Figure 5).

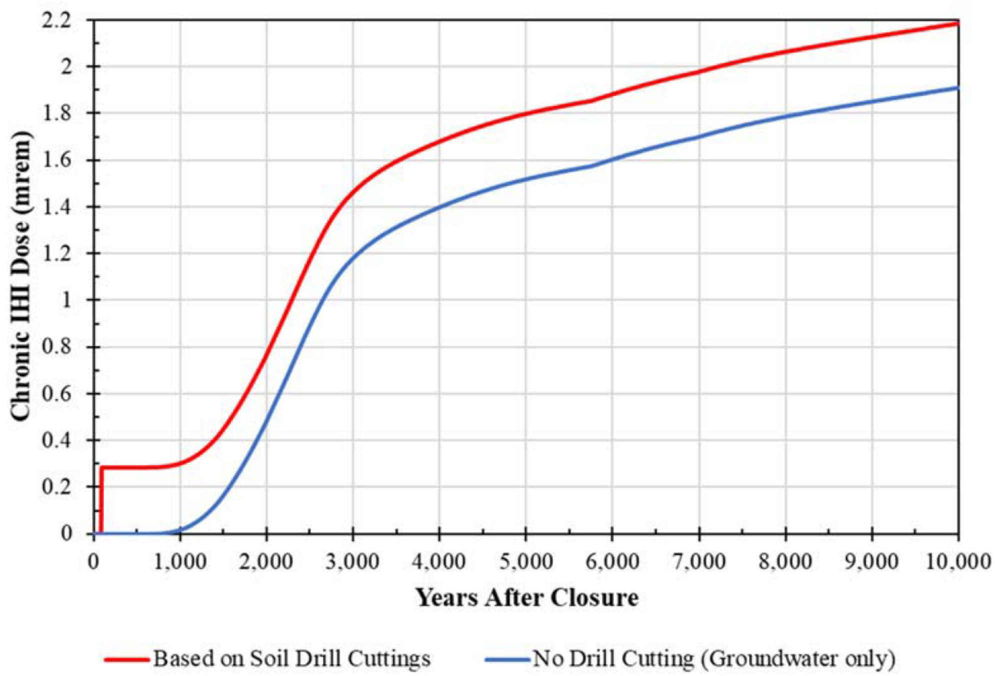

Figure 5. Total Projected Dose and Groundwater-Based Projected Dose from Chronic Exposure in the Soil-Drilling Scenario (Figure 6.4-3 in the 2020 SDF PA)

Grout Drill Cuttings

The DOE projected larger doses from chronic exposure to drill cuttings for an individual who could live at the SDF after another individual drills through a disposal structure (see Figure 6, below). As for acute exposure, the largest projected doses were associated with drilling through a 375-foot disposal structure, followed by a 150-foot disposal structure, SDS 4, and SDS 1. All the doses that the DOE projected were less than the 5 mSv/yr (500 mrem/yr) dose constraint the NRC uses to evaluate compliance with the 10 CFR 61.42 PO. For all the disposal structures, the DOE projected that over 90 percent of the dose would be attributable to Tc-99 and 5 percent of the dose would be attributable to Pu-239. The DOE projected the main exposure pathway would be ingestion of plants grown in soil contaminated by being mixed with drill cuttings.

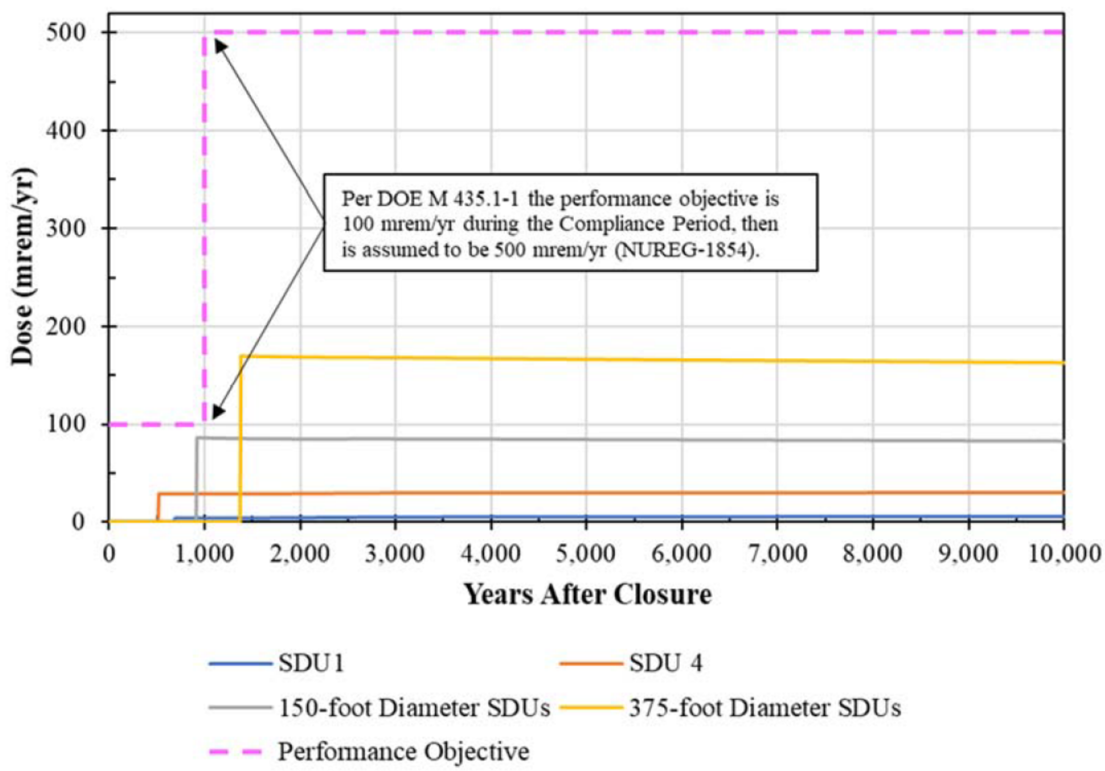

Figure 6. Projected Dose from Chronic Exposure in the Grout-Drilling Scenario (Figure 6.4-4 in the 2020 SDF PA)

Alternative Well Locations

To assess the importance of the selected well location, the DOE modeled the dose to a chronically exposed inadvertent intruder at each of seven intruder well locations on the SDF. As shown in Figure 7, below, the projected dose was greatest when the DOE used radionuclide concentrations from water at the 1-m SDF boundary. Although those dose projections do not reflect the revised process for developing a soil drill cuttings source term to account for radionuclide sorption to soil, the NRC staff expects that the relative magnitudes of the projected doses at the different well locations should be similar to the values shown in Figure 7.

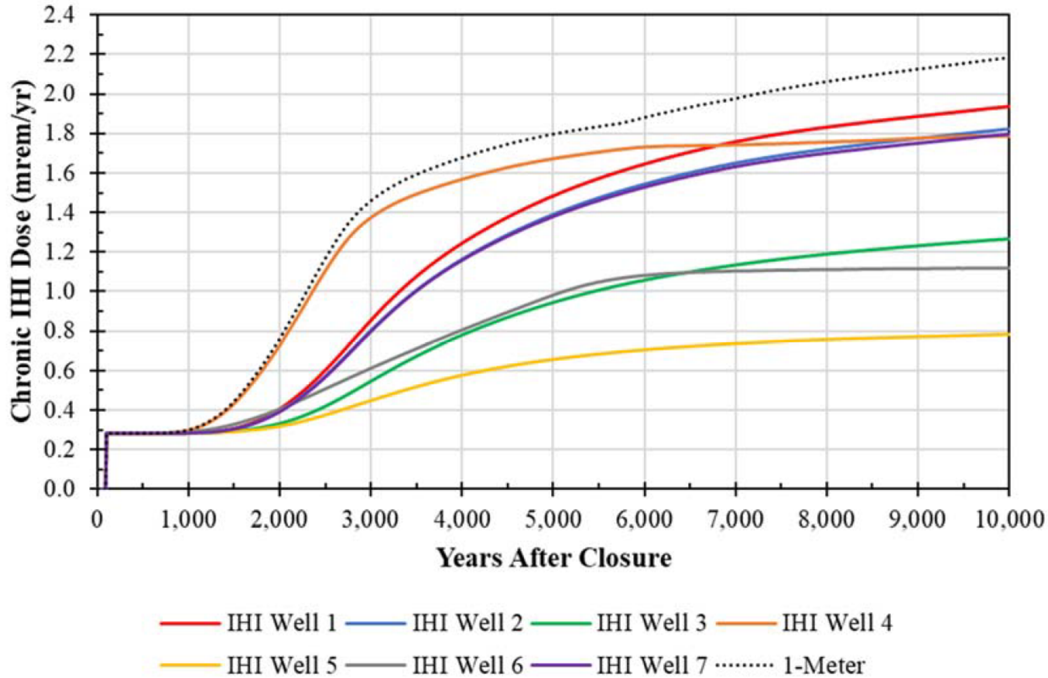

Figure 7. Projected Dose from Chronic Exposure in the Soil-Drilling Scenario at Various Well Locations (Figure 6.5-1 in the 2020 SDF PA)

3.7 Deterministic Sensitivity Analyses

The DOE conducted four deterministic intrusion sensitivity analyses in the 2020 SDF PA and one additional deterministic sensitivity analysis in a DOE response to an NRC RAI question. The analyses in the PA included: (1) benchmarking for soil drill cuttings,[4] (2) evaluation of intrusion timing into soil near a disposal structure, (3) comparison of Central Scenario Cases (i.e., Realistic and Pessimistic Cases), and (4) qualitative evaluation of invertebrate intrusion. In response to an NRC RAI question, the DOE also evaluated the effect of human intrusion through a disposal structure on the water flow and radionuclide transport into the saturated zone.

The DOE based all the deterministic sensitivity analyses for intrusion on the dose to a chronically exposed individual in a soil-drilling scenario. The DOE indicated it used chronic exposures because those dose projections were greater than the projected doses to an acutely exposed inadvertent intruder. The DOE indicated it based the deterministic sensitivity analyses on exposure to soil drill cuttings rather than saltstone drill cuttings because it expected drilling into soil to be more likely than drilling into a disposal structure.

3.7.1 Benchmarking for Soil Drill Cuttings

As described in more detail in the NRC staff TRR on Model Integration (ML23017A090), the DOE created both a detailed deterministic 2020 SDF PA model and a more abstracted model that could be run either deterministically or probabilistically. The DOE used the detailed 2020 SDF PA model for the compliance demonstration and the abstracted model for the probabilistic

[4] The DOE referred to this analysis both as "additional benchmarking" and as a deterministic sensitivity analysis (see Section 6.7.1 in the 2020 SDF PA).

analysis and some of the deterministic sensitivity analyses. For the detailed model, the DOE used a combination of software codes to model different aspects of the SDF and exposure pathways for an offsite member of the public or inadvertent intruder. The 2020 SDF PA model used the PORFLOW software to model radionuclide release from saltstone and transport through the disposal structure, vadose zone, and in the aquifers underlying the SDF. For that reason, the DOE sometimes referred to the deterministic 2020 SDF PA model as a "PORFLOW-based model" even though other parts of the 2020 SDF PA model were implemented with other software. For example, for the detailed 2020 SDF PA model, the DOE used the GoldSim modeling platform to model exposure pathways in the biosphere (e.g., food-chain transport, inhalation of resuspended particles, direct exposure). For the abstracted model, the DOE developed the entire model in the GoldSim modeling platform. The DOE referred to that model as the "SDF GoldSim Model" to distinguish it from the GoldSim code that only modeled exposure pathways in the biosphere. The DOE referred to the GoldSim code that modeled exposure pathways in the biosphere as the "Dose and Exposure Pathways Model." Both the detailed 2020 SDF PA model and the abstracted GoldSim model used the same code to model exposure pathways in the biosphere. The NRC staff reviewed that model in a separate TRR (ML23017A113).

The DOE benchmarked the SDF GoldSim Model results (i.e., when the DOE ran the SDF GoldSim Model in deterministic mode) by comparing the SDF GoldSim Model results with dose projections from the detailed 2020 SDF PA model. The NRC staff reviewed benchmarking for an offsite member of the public in a TRR on Model Integration (ML23017A090). In that TRR, the NRC staff determined that the DOE benchmarking demonstrated that the abstracted SDF GoldSim Model provided a reliable abstraction of the more detailed 2020 SDF PA model. The DOE benchmarking for the intrusion analysis relied in part on the DOE benchmarking for the offsite member of the public. The DOE also performed two additional types of comparisons to benchmark the abstracted SDF GoldSim Model for the intrusion analyses: (1) benchmarking groundwater pathway doses for a chronically exposed inadvertent intruder located at a 1-m (3.3-ft) well and (2) demonstrating that the additional dose projection from radionuclides in drill cuttings mixed with garden soil affected the projected dose from the detailed deterministic 2020 SDF PA model and abstracted SDF GoldSim Model the same way.

The DOE determined that the projected doses to a chronically exposed inadvertent intruder from the PORFLOW-based models and the SDF GoldSim Model were indistinguishable for the first 2,000 years after site closure, when drill cuttings dominated the projected dose to a chronically exposed inadvertent intruder. After 2,000 years, the projected doses from the SDF GoldSim Model were greater than the projected doses from the PORFLOW-based models. The DOE expected that difference because of the more conservative release model for I-129 implemented in the GoldSim SDF Model. That difference was similar to the difference between the two models that the DOE observed for an offsite member of the public and the NRC staff addressed that difference in the Model Integration TRR (ML23017A090).

3.7.2 Time of Intrusion

The DOE used the SDF GoldSim Model deterministically to test the sensitivity of the projected dose to a chronically exposed individual in the soil-drilling scenario to the modeled time of intrusion. The sensitivity analysis differed from the Compliance Case in how the DOE determined the radionuclide concentrations in groundwater. For the Compliance Case, the DOE used the peak groundwater concentrations at any depth at any time within 20,000 years of SDF closure. In the deterministic sensitivity analysis for the time of intrusion, the DOE modeled intrusion at 1,000, 5,000, and 10,000 years after site closure using groundwater concentrations from those times. The DOE used the maximum groundwater concentration at any depth at any location either 1 m (3.3 ft) from the SDF boundary or at the seven pre-determined intruder well locations.

As in the Compliance Case, the DOE used the groundwater concentrations both to model groundwater-dependent pathways and determine the concentrations of radionuclides in soil drill cuttings. Because the DOE performed the time of intrusion sensitivity analysis before revising the inventory in the soil drill cuttings to account for radionuclide sorption to soils, the NRC staff expects the recalculated results would be slightly greater if the DOE conducted the time of intrusion sensitivity analysis again with the revised inventory (e.g., see Figure 4 above). However, the difference should not change the relative effects of the time of intrusion in the sensitivity analysis because the dominant radionuclides in the soil drill cuttings scenario did not change when the DOE accounted for radionuclide sorption to soil.

The DOE found that the changing the time of intrusion had a minimal effect on the projected dose to a chronically exposed inadvertent intruder in the soil drill cuttings scenario. Specifically, intrusion at 1,000, 5,000 and 10,000 years after site closure produced results that were approximately 10 percent less than the Compliance Case projections, with negligible differences between each other. The DOE also determined that intrusion at those alternative times yielded a similar result to the groundwater-only result (which the DOE referred to as the “no intrusion” case in this analysis).

3.7.3 Central Scenario Intrusion Doses

The DOE used parameters from the Realistic and Pessimistic Central Scenario Cases for an offsite member of the public to create two deterministic sensitivity cases for the intrusion analysis. Although the DOE plans to maintain control of the SRS in perpetuity and considers intrusion to be unlikely, the DOE referred to those cases as Central Scenario intrusion cases, in accordance with the DOE terminology for an offsite member of the public. Table 5.8-1 in the 2020 SDF PA lists the following areas as key differences between the Central Scenario Cases:

- inventory;
- cementitious material properties;
- iodine sorption coefficients in chemically reducing saltstone;
- technetium solubility in chemically reducing saltstone;
- infiltration rates;
- cementitious degradation rates;
- chemical reducing capacity of saltstone;
- chemical reducing capacity of disposal structure concrete;
- pore volume exchanges for saltstone transition from chemically reducing to oxidizing; and

- human ingestion and inhalation rates.

The NRC staff reviewed the values the DOE chose for the Realistic, Compliance, and Pessimistic Cases in TRRs related to each topic area. For example, the NRC staff reviewed the inventory values for Central Scenario Cases in an NRC TRR on the Inventory for the 2020 SDF PA (ML23017A087) and the human ingestion and inhalation rate in the Dose and Exposure Pathways Model TRR (ML23017A113). For parameters that are specific to the intrusion analysis (e.g., drilling time), the DOE only selected one deterministic value. For example, the intrusion scenario for drilling through a disposal structure uses one set of radionuclide activities brought to the land surface (i.e., there are not separate Realistic, Compliance, and Pessimistic drill cutting inventories). Therefore, this TRR does not include a review of the Realistic and Pessimist Case parameter values, because they are covered in TRRs for each topic area.

Figure 8 shows a factor of 29 difference between the Realistic and Pessimistic Case peak projected dose within 10,000 years of site closure for a chronically exposed inadvertent intruder in the soil-drilling scenario (i.e., 0.0051 mSv/yr [0.51 mrem/yr] versus 0.15 mSv/yr [15 mrem/yr]). Those numerical results correspond to the soil drill cuttings inventory before the revision to account for soil sorption, which increased the projected dose to a chronically exposed inadvertent intruder by approximately 50 percent in the Compliance Case (see Figure 4).

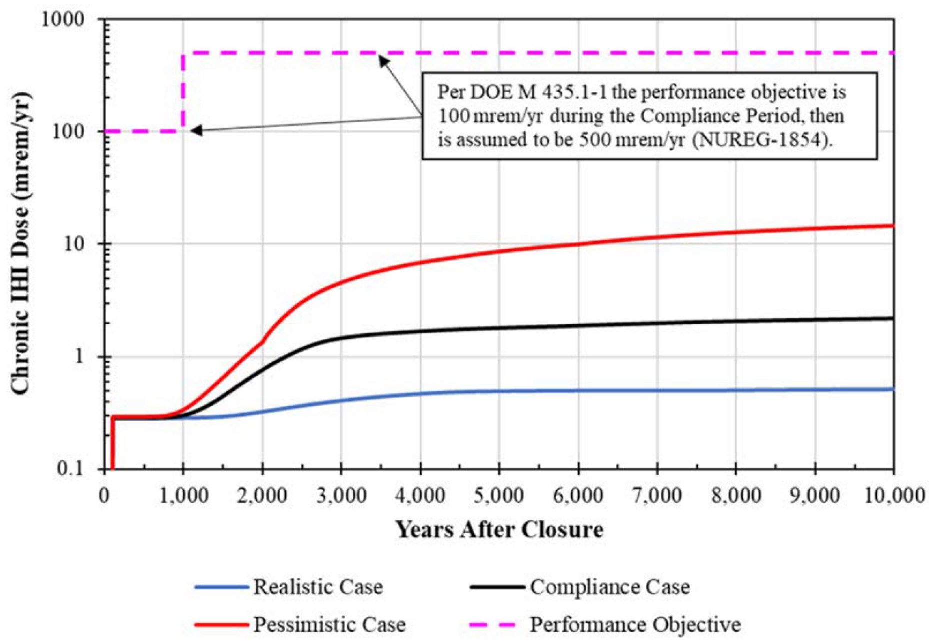

Figure 8. Central Scenario Dose Projections for Chronic Exposure in a Soil-Drilling Scenario (Figure 6.7-3 in the 2020 SDF PA)

3.7.4 Invertebrate Intrusion

The DOE considered potential sources of biotic intrusion at the SDF. The DOE determined that ants were unlikely to penetrate beyond the HDPE) layer in the Closure Cap because elevated moisture above the HDPE would discourage ants from burrowing into soil directly above the HDPE. In addition, the DOE determined that the potential dose to a human as a result of ants bringing contaminated soil or degraded saltstone to the surface could be bounded by the results of the human intrusion scenarios.

3.7.5 Effects of Human Intrusion through a Disposal Structure on Radionuclide Transport

In response to an NRC RAI question, the DOE evaluated the potential effect of human intrusion through a disposal structure on near-field flow and radionuclide transport at the SDF (SRR-CWDA-2021-00047, Rev. 1). In that response, the DOE indicated that intrusion from an individual drilling a well through the Closure Cap and through a disposal structure would not have a significant effect on water flow through saltstone. The DOE based that determination on regulations of the South Carolina Department of Health and Environmental Control (SCDHEC) that require that the DOE hydraulically isolate the well during installation and operation and should ensure its continued isolation after abandonment. The DOE summarized relevant regulations from the SCDHEC regulation R.61071, "Well Standards," to support that determination. The DOE also summarized typical well installation procedures.

In addition, the DOE used the PORFLOW Vadose Zone Flow Model and Vadose Zone Transport Model to represent the effects of a well installed through the center of SDS 7 (referred to as the "Well Intrusion Case" in this TRR). Although the DOE expects that the most likely size of a water well would be a 10-cm (3.9-in) diameter well in a 20-cm (7.9-in) diameter boring, the spatial resolution of the Vadose Zone Flow Model and the Vadose Zone Transport model imposed a minimum modeled well diameter of 3.4 m (11 ft). The DOE assumed the Closure Cap would be sufficiently degraded by the well to allow water flow through the cap at the natural deep infiltration rate (i.e., 417.8 mm/yr [16.4 in/yr]). The DOE applied that infiltration rate above the Lower Lateral Drainage Layer and HDPE/Geosynthetic Clay Liner composite barrier above a disposal structure. The DOE indicated that the case was identical to the "No Closure Cap" sensitivity analysis case (see the NRC staff TRR on Near-Field Flow and Transport (ML23017A086), except for the inclusion of the well through the disposal structure.

The DOE quantified the results of the sensitivity analyses as radionuclide fluxes to the saturated zone. To provide insight into the effects on the projected dose, the DOE compared the modeled fluxes to the fluxes from the "No Closure Cap" sensitivity analysis. The DOE determined that the well intrusion sensitivity analysis caused radionuclide fluxes approximately 33 percent greater than the No Closure Cap sensitivity analysis. The DOE indicated that factor could be used to scale up the projected doses from the No Closure Cap Case to the Well Intrusion Case. In the DOE document SRR-CWDA-2021-00047, Rev. 1, the DOE indicated that the peak dose to a chronically exposed inadvertent intruder at the 1-m (3.3-ft) site boundary from the No Closure Cap Case would be 0.18 mSv/yr (18 mrem/yr) at approximately 1,900 years after site closure. Therefore, the DOE scaling factor of 33 percent greater radionuclide fluxes in the Well Intrusion Case would imply a peak dose of 0.24 mSv/yr (24 mrem/yr) in the Well Intrusion Case.

3.8 Probabilistic Sensitivity and Uncertainty Analyses

The DOE conducted probabilistic sensitivity and uncertainty analyses for the intrusion analysis based on chronic exposure to an inadvertent intruder 1 m (3.3 ft) from the SDF boundary in a soil-drilling scenario. The DOE indicated that it selected that intrusion exposure scenario for probabilistic analysis because the DOE expected it to be the most likely intrusion exposure scenario. In addition, the DOE noted that the projected dose at a 1-m well was greater than the projected dose at the pre-selected intrusion well locations. The DOE did not provide a reason that the DOE did not provide probabilistic results for acute exposure during well drilling. However, the projected dose to a chronically exposed intruder at a 1-m well location was greater than the projected dose due to acute exposure during well drilling into soil at any location (i.e., 1 m [3.3 ft] from the SDF boundary or a pre-selected intruder well location). In the 2020 SDF PA, the DOE indicted that the DOE did not provide a probabilistic analysis for grout-drilling scenarios because the DOE considered drilling into saltstone to be unlikely.

3.8.1 Stochastic Parameter Distributions

The DOE used the same stochastic parameter distributions for the intrusion analysis that the DOE used for analyses for an offsite member of the public. Parameters that only affect the intrusion analysis (e.g., duration of time drilling, volumes of drill cuttings) only had deterministic values in the DOE intrusion analysis for the 2020 SDF PA. The DOE created a stochastic distribution for well depth; however, the DOE did not use that distribution in the probabilistic intrusion analyses and provided the distribution for information only. There are three stochastic distributions that affect the intrusion analysis differently from the analysis for a member of the public: the till depth, the garden area, and the time of intrusion.

Both the till depth and the garden area affect the radionuclide concentrations in the garden soil due to mixing with drill cuttings because the volume of garden soil mixed with the drill cuttings is modeled as the till depth multiplied by the garden area (i.e., see Equation 2, above). For example, in the deterministic analysis, the modeled garden soil volume is 0.15 m × 100 m^2 = 15 m^3 (0.49 ft x 1080 ft^2 = 161 ft^2). In the probabilistic analysis, the DOE multiplied the deterministic value of the garden area (i.e., 100 m^2 [1080 ft^2]) by a stochastic unitless multiplier. The DOE sampled the unitless multiplier for the garden area from a triangular distribution with a minimum and mode both equal to one and a maximum of ten. Therefore, the in the probabilistic SDF GoldSim Model, the DOE used a garden area that ranged from 100 m^2 (1080 ft^2) to 1000 m^2 (10,800 ft^2). In the SDF 2020 SDF PA, the DOE did not alter the modeled time spent in the garden based on the garden area. Similarly, the DOE used DCFs corresponding to an infinite area irrespective of the garden area. However, the DOE did adjust the radionuclide concentrations in garden soil based on the garden area such that smaller gardens had larger radionuclide concentrations, as shown in Equation 1 in this TRR. In addition, the DOE adjusted fraction of produce grown locally based on the garden area such that, in general, larger gardens resulted in a larger modeled fraction of produce grown locally and smaller gardens resulted in a smaller fraction of produce grown locally. The NRC staff addressed the equation the DOE used to adjust the local fraction of produce in a separate TRR on the DOE Dose and Exposure Pathways Model (ML23017A113).

Because the probabilistic SDF GoldSim Model implements parametric uncertainty by multiplying the deterministic parameter values by unitless stochastic distributions (i.e., uncertainty multipliers), the model can represent same parameter probabilistically in some parts of the model and deterministically in other parts of the model during the same model run. For example, the SDF GoldSim Model includes a unitless uncertainty multiplier for the till depth represented with a triangular distribution with a minimum and mode both equal to 1 and a maximum equal to 4) (i.e., the resulting till depths were distributed with a triangular distribution that had a minimum and mode of 0.15 m (0.49 ft) and a maximum equal to 0.60 m (2.0 ft)). However, the model uses that uncertainty distribution with some instances of the till depth parameter and not others. Specifically, the model uses the stochastic multiplier for the till depth in the calculation of the leach rate of radionuclides from irrigated soil. However, the model does not include the stochastic multiplier for till depth in the calculation of radionuclide concentrations in garden soil mixed with drill cuttings. Therefore, the sensitivity to the model on the till depth only reflects the effect of the till depth on the leach rate, even though the till depth is used in other parts of the model.

The time of intrusion at the SDF could affect exposures because radionuclide concentrations in soil would depend on groundwater concentrations, which vary in time. As indicated in Section 3.7.2, in the Compliance Case the DOE made a conservative modeling simplification by using the peak radionuclide concentrations in groundwater, irrespective of the time after closure, to calculate radionuclide concentrations in soil. To evaluate the effect of the time of intrusion in the probabilistic analysis, the DOE used the time-dependent groundwater concentrations projected by the Aquifer Transport Model. As in the Compliance Case, the DOE used the radionuclide concentrations from the location with the highest concentrations, irrespective of depth. The DOE sampled the time of intrusion from a uniform distribution beginning at the end of institutional controls (i.e., 100 years) and running through the end of the simulation duration[5] (i.e., 20,000 years for most simulations).

As discussed in Section 3.4.2 of this TRR, the intrusion analysis in the 2020 SDF PA did not account for radionuclide sorption to soil. For the Compliance Case, the DOE revised that method in response to an NRC RAI question. However, for the probabilistic analysis, the DOE did not revise the modeled inventory in the soil drill cuttings.

3.8.2 Probabilistic Sensitivity Analysis Results

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. 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.

Figure 9 shows the PRCC for the variables with the top 12 absolute magnitudes during the 10,000 years after site closure, based on the projected dose to a chronically exposed inadvertent intruder along the 1-m SDF boundary. Comparison of Figure 9, below, with Figure 5.7-10 in the 2020 SDF PA shows that the results for a chronically exposed inadvertent intruder at the 1-m SDF boundary are very similar to the results for an offsite member of the public. Specifically, nine of the top twelve PRCCs for the chronically exposed inadvertent intruder were also in the top 12 PRCCs for an offsite member of the public. In addition, the parameter with the largest positive correlation to the projected dose for most of the 10,000 years after SDF closure for both analyses was the infiltration and the parameter with the largest negative correlation to the projected dose for the first several hundred years after site closure for both analyses was the thickness of the vadose zone under SDS 9. Of the variables that differed, the vadose zone thickness for SDS 4, vadose zone thickness for SDS 7, and sorption coefficient (referred to as a “K_d” in Figure 9 in this TRR) for Tc in sand were more important for a chronically exposed inadvertent intruder. The leachate-impacted sorption coefficient for iodine in

[5] The DOE sampled from a distribution ranging from 0 years to 20,000 years and added 100 years to account for institutional controls. That choice resulted in 0.5 percent of the realizations not sampling an intrusion event during the simulation period.

sand, unimpacted sorption coefficient for iodine in sand, and saturated width under SDS 7 were more important for an offsite member of the public.

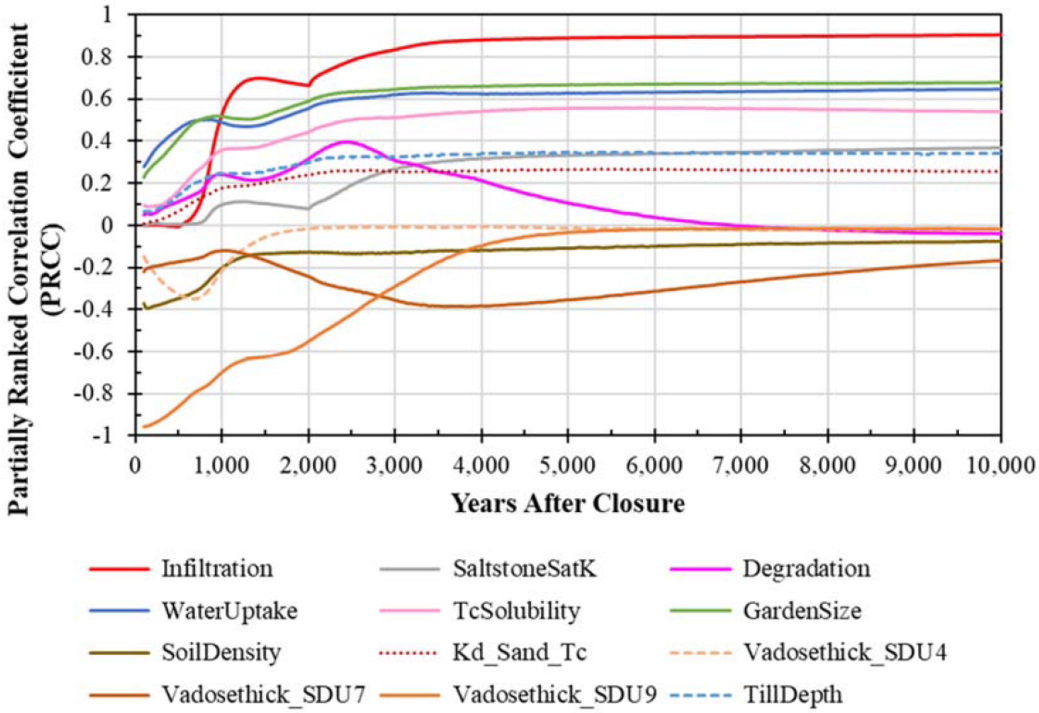

Figure 9. PRCCs for the Projected Dose from Chronic Exposure in a Soil-Drilling Scenario at the 1-m SDF boundary (Figure 6.6-6 in the 2020 SDF PA)

Table 6 compares the top eight SRRC results for the chronically exposed inadvertent intruder 1-m (3.3-ft) from the SDF boundary with the top eight SRRC results for a member of the public. As shown in the table, the same eight parameters had the most influence on both dose projections, with only a change in order of the seventh and eighth parameters. In Table 6, a positive SRRC indicates that the projected dose is positively correlated with the parameter value over the tested range of the parameter, and a negative value of the SRRC indicates that the projected dose is negatively correlated with the parameter value over the tested range of the parameter.

3.8.3 Probabilistic Uncertainty Analysis Results

The DOE determined that 99 percent of the projected peak doses for a chronically exposed individual exposed to soil drill cuttings were between 0.005 mSv/yr (0.5 mrem/yr) and 0.5 mrem/yr (50 mrem/yr) within 20,000 years after closure. Table 7, below, provides statistics of the projected peak doses within 1,000, 10,000, and 20,000 years of site closure for a chronically exposed individual exposed to soil drill cuttings. The table provides the mean, median, 5th percentile, and 95th percentile peak projected doses from the probabilistic GoldSim model. In addition, it provides the projected peak doses from the same GoldSim model run deterministically. For comparison, the table also provides the projected peak doses from the deterministic Compliance Case based on PORFLOW models. The DOE calculated the values in Table 7 prior to revising the soil drill cuttings inventory, as described in Section 3.4.2 in this TRR.

Table 6. Parameters with the Largest Magnitude SRRCs at 10,000 Years after SDF Closure

Inadvertent Intruder, Chronic Exposure [a]		Offsite Member of the Public [b]	
Parameter	**SRRC (unitless)**	**Parameter**	**SRRC (unitless)**
Infiltration	0.720	Infiltration	0.723
Garden area	0.318	Garden area	0.313
Water intake	0.291	Water intake	0.291
Tc solubility	0.219	Tc solubility	0.216
Saturated hydraulic conductivity of saltstone	0.139	Saturated hydraulic conductivity of saltstone	0.137
Width of the saturated zone under SDS 7	-0.133	Width of the saturated zone under SDS 7	-0.126
Width of the saturated zone under SDS 6	0.115	Till depth	0.126
Till depth	0.127	Width of the saturated zone under SDS 6	0.112

[a] from Table 6.6-3 of the 2020 SDF PA
[b] from Table 5.7-8 of the 2020 SDF PA

Table 7. Statistics of the Projected Peak Dose from Chronic Exposure in a Soil-Drilling Scenario (adapted from Table 6.6-1 in the 2020 SDF PA)

Statistic	Projected Peak Dose (mrem/yr)		
	Within 1,000 years of Closure	Within 10,000 years of Closure	Within 20,000 years of Closure
Mean	0.050	6.9	7.1
95th Percentile	0.16	21	22
Median	0.030	4.5	4.6
5th Percentile	0.00655	0.99	1.0
Benchmarked GoldSim Model Run Deterministically	0.30	3.1	3.2
PORFLOW-based Compliance Case (always deterministic)	0.30	2.2	2.5

<u>4.0 NRC Staff Evaluation</u>

4.1 Overview

The NRC staff reviewed the DOE inadvertent intrusion analyses included with the 2020 SDF PA in support of the NRC staff's assessment of compliance with the 10 CFR Part 61 Performance Objective for the Protection of Individuals Against Inadvertent Intrusion (10 CFR 61.42). In addition, the NRC staff used insights from this review to develop recommended changes to the NRC SDF Monitoring Plan (see italics below). Section 7 in this TRR provides a summary of the recommended changes.

The NRC staff found the scope of the DOE intrusion analyses, including alternative intrusion exposure scenarios, to be acceptable for determining compliance with the 10 CFR 61.42 PO because the group of intrusion analyses collectively included all risk significant intrusion exposure scenarios (see Section 4.3 in this TRR) and source terms (see Section 4.4 in this TRR). In addition, the NRC staff found the DOE appropriately evaluated the effect of intrusion on near-field flow (see Section 4.6 in this TRR). The NRC staff did not agree with the DOE choice to use the soil-drilling scenario as the case to demonstrate compliance with the 10 CFR 61.42 PO because the NRC staff found the saltstone grout-drilling case to be plausible (see Section 4.3 in this TRR). However, the NRC staff found that the DOE analysis of an alternative case to evaluate acute and chronic exposures to saltstone grout drill cuttings provided sufficient information for the NRC staff to evaluate compliance with the NRC performance objective for protection of individuals against inadvertent intrusion (i.e., 10 CFR 61.42).

The NRC staff found the DOE modeled intrusion times were acceptable for two reasons: (1) the DOE made either conservative or reasonable choices in deterministic analyses; and (2) the DOE evaluated the effect of changing the intrusion time in sensitivity analyses. For soil-drilling cases, the NRC staff found modeling intrusion at the end of institutional controls to be a conservative choice because it is the earliest plausible time for intrusion and modeling later times of intrusion resulted in lower projected doses. For the grout-drilling cases, the NRC staff found modeling intrusion after a disposal structure roof was completely degraded to be acceptable because the rebar-reinforced disposal structure roofs could reasonably be expected to deter drillers until the roofs are significantly degraded. Section 4.3 in this TRR describes an NRC staff evaluation of drilling at an earlier time, which the NRC staff used to risk-inform the intrusion analysis.

As indicated in Section 2.0 of this TRR, the NRC SDF Monitoring Plan does not include a MA for Inadvertent Intrusion. Instead, the NRC staff identified several monitoring factors that related to the POs in both 10 CFR 61.41 and 10 CFR 61.42. In contrast, in this review, the NRC staff recommended adding monitoring factors that are specifically related to intrusion to the NRC Monitoring Plan. Therefore, for clarity, the NRC staff recommends that the next revision of the SDF Monitoring Plan include a MA for Inadvertent Intrusion.

> ***INTA-01*** *The NRC staff recommends opening a new monitoring area entitled "Inadvertent Intrusion" for monitoring factors related primarily to the protection of individuals from inadvertent intrusion under the 10 CFR 61.42 Performance Objective.*

4.2 Barriers to Intrusion

The NRC staff determined that the barriers to intrusion at the SDF are generally consistent with the modeled intrusion scenarios. The DOE assumption that a disposal depth greater than 3 m (10 ft) would exclude intrusion for construction of a dwelling was consistent with the NRC guidance in NUREG-2175, Chapter 4. The NRC staff found the assumption that the disposal structures would remain more than 3 m (10 ft) below the land surface to be acceptable because the initial depth of disposal structure roofs is sufficient to maintain more than 3 m (10 ft) of soil above the disposal structures even if the erosion barrier fails within 10,000 years of SDF closure (see the NRC TRR on percolation through and potential erosion near the Closure Cap [ML23017A083]).

The NRC staff found the DOE decision to assume the disposal structure roofs would discourage human intrusion while the roofs are intact was reasonable because: (1) the roofs are reinforced with rebar and (2) the concrete roofs are harder than saltstone and significantly harder than the local soil. However, the NRC staff determined that those reasons were not sufficient to preclude consideration of drilling into a disposal structure at the end of institutional controls (i.e., 100 years after SDF closure). The NRC staff made that determination because a survey of well drillers near the SRS indicated that, although a disposal structure would be harder to drill through than normal SRS soil, a well driller is unlikely to give up a job if the client is willing to pay for extra drilling time (ML20349G094). The NRC staff expects that a well driller who encounters a disposal structure at the SDF might move a drill rig once or twice to find softer soil. For a smaller disposal structure, relocating the drill rig is likely to result in drilling into soil between the disposal structures. However, for a 375-foot disposal structure, a driller could move the drill rig once or twice and still be located above the same disposal structure. Therefore, the NRC staff performed independent analyses with the DOE GoldSim model for inadvertent intrusion to assess the projected dose to a chronically exposed individual in a grout-drilling scenario at 100 years after SDF closure (see Section 4.3 in this TRR).

4.3 Intrusion Exposure Scenarios

The NRC staff finds the combination of the DOE soil-drilling and grout-drilling scenarios acceptable for demonstrating compliance with the 10 CFR 61.42 PO because the DOE analyses of those intrusion exposure scenarios and the accompanying SDF GoldSim intrusion model provided enough information for the NRC staff to make a compliance determination. However, the NRC staff determined the DOE Compliance Case was not appropriate to use to assess compliance with the 10 CFR 61.42 PO. Although the DOE indicated that it would be highly unlikely for an individual to drill a well directly into saltstone grout, the NRC staff agreed with the DOE choice to evaluate the intrusion exposure scenario because of the large uncertainty in the degraded properties of disposal structure concrete and saltstone grout within 10,000 years of SDF closure. Furthermore, degradation beyond the degradation the DOE expects could increase the chance of intrusion into a disposal structure. Based on the long half-lives of the key radionuclides in the intrusion analyses for the SDF (e.g., Tc-99, I-129, Pu-239), the NRC staff determined that it would use drilling into saltstone to assess compliance with the 10 CFR 61.42 PO.

Furthermore, the NRC staff determined that the DOE did not evaluate two plausible intrusion exposure scenarios that should be considered: (1) an individual drilling into a disposal structure at the end of the institutional control period, and (2) an individual being exposed to water from a shallow well with radionuclides concentrating above the Tan Clay Confining Zone. The NRC staff relied on independent analyses to evaluate those scenarios, as described further below.

As describe in Section 4.2, the NRC staff determined that it is necessary to evaluate the risk significance of drilling into a disposal structure at the end of the institutional control period. To consider the potential dose to a chronically exposed inadvertent intruder from a grout-drilling scenario at the end of the institutional control period, the NRC staff used the DOE SDF GoldSim model for intrusion into SDS 7, which the DOE provided with its response to the NRC staff's first set RAI questions (SRR-CWDA-2021-00047, Rev. 1). When the staff changed the time of intrusion in that model to 100 years after SDF closure, the resulting peak projected dose to a chronically exposed individual increased from 1.7 mSv/yr (170 mrem/yr) to 24 mSv/yr (2.4 rem/yr). That dose was primarily due to Sr-90. Using the same GoldSim model, the NRC staff determined that the projected peak dose decreased to 0.5 mSv/yr (500 mrem/yr) at 190 years after SDF closure. Although the projected peak dose at 100 years was greater than dose limit of 0.5 mSv/yr (500 mrem/yr), the NRC staff determined that the projected dose was acceptable for two reasons. First, the NRC staff expects that the disposal structure roof should present a significant barrier to drilling at 100 years after site closure. In addition, the NRC staff expects that many of the engineered materials (e.g., HDPE, rebar) in the Closure Cap and above the disposal structure should be recognizable. Second, the NRC staff expects the DOE is likely to maintain control of the site for several decades beyond the credited institutional control period of 100 years, during which time the projected peak dose would decrease to 5 mSv/yr (500 mrem/yr).

The NRC staff determined that the DOE should consider an alternative conceptual model in which radionuclides concentrate in the Upper Three Runs Aquifer (UTRA) Upper Aquifer Zone (UAZ). The NRC staff described that alternative conceptual model in more detail in a TRR on Future Scenarios and Site Conceptual Models (ML23017A088). In brief, in that conceptual model radionuclides would concentrate in the UTRA-UAZ because the Tan Clay Confining Layer is more confining than the DOE modeled in the Aquifer Transport Model. An individual could then be exposed to that water if the individual drilled a shallow well into the UTRA-UAZ. Although the DOE used the highest radionuclide concentrations of any modeled aquifer as input to the Dose Model, those radionuclide concentrations would not bound the concentrations that could occur in the UTRA-UAZ if leachate from the disposal structures primarily flowed to that layer instead of flowing to the UTRA Lower Aquifer Zone (LAZ), as the DOE modeled in the Aquifer Transport Model. Based on the DOE dose projection in Figure 5 in this TRR, groundwater that is approximately 250 times more concentrated than the groundwater in the UTRA-LAZ could result in projected peak doses of approximately 5 mSv/yr (500 mrem/yr) for a chronically exposed individual in the soil-drilling scenario. Because that alternative conceptual model affects the projected dose to an offsite member of the public as well as an inadvertent intruder, the NRC staff recommended the creation of a new MF to evaluate the DOE development of information related to this alternative conceptual model in a separate TRR on Future Scenarios and Site Conceptual Models (ML23017A088).

The NRC staff found the DOE exclusion of exhumation of saltstone for construction of a residence to be acceptable because of the depth of disposal of the saltstone grout. The NRC staff agreed it is likely that the erosion barrier would maintain greater than 3.0 m (10 feet) of clean material above the disposal structures at the thinnest cap locations and that most of the disposal structures will be covered by more than 3.0 (10 feet) of clean material because of the Closure Cap slope. The disposal structure roofs will provide between 0.15 and 0.3 m (6.0 and 12 in) of clean material above saltstone grout, depending on the disposal structure. SDS 1, SDS 4, SDS 3, and SDS 5 also will have a layer of clean grout between the disposal structures and the roofs. Although the disposal structures also may have a layer of clean grout between the saltstone grout and the disposal structure roofs, the DOE has not finalized that decision.

The NRC staff found the DOE exclusion of waste exhumation due to mining to be acceptable for a combination of reasons. The DOE indicated that mining was not plausible because of limited economically viable resources onsite. However, the DOE determined that it could be economically viable to excavate a borrow pit for sand near the SDF. The DOE did not provide a basis for excluding excavating a borrow pit for sand from the intrusion analysis. However, the NRC staff expects that excavation of a borrow pit would expose enough of the disposal structures to make it clear that the area was a poor location for a borrow pit. In addition, as the NRC staff determined for a large construction project, the NRC staff also expects that the discovery of the large, engineered structures in an area the size of an excavation for a borrow pit would prompt further investigation that would preclude chronic exposures. Therefore, the NRC staff expects that waste excavation for mining is a very unlikely intrusion exposure scenario.

Although the DOE screened in FEP 3.3.07 for “Ancillary Equipment and Piping/Transfer Lines,” the DOE determined that sensitivity analyses related to that FEP could be performed after the DOE further developed SDF closure plans. The NRC staff finds that deferral to be acceptable under the 10 CFR 61.42 PO because the NRC staff expects that the DOE analysis for drilling through a disposal structure bounds the projected dose from drilling into a transfer line. The NRC staff determined that comparison required a quantitative evaluation because the NRC staff assumed that an individual could encounter a transfer line as a temporary obstacle during mud rotary drilling in soil. In contrast, the DOE assumed an individual would use coring bit to drill into a disposal structure. Therefore, it was not immediately apparent to the NRC staff that using a coring bit to drill through a disposal structure would generate a larger volume of drill cuttings than using a rotary drill to drill through a transfer line. Therefore, the NRC staff estimated the amount of grout an individual would exhume by drilling through a transfer line filled with grout or decontaminated salt waste by calculating the volume of grout that could be contained in a 0.30 m (1 ft) diameter transfer pipe intersected by a 0.3 m (1 ft) diameter well. The volume of two cylinders with the same radius that intersect as shown in Figure 10 is given by:

$$V = \frac{16r^3}{3} \qquad \text{Eqn. 3}$$

Where
V is the volume of the intersection and
r is the radius of the cylinders.

Based on Equation 3, the volume of grout in an abandoned transfer line on the SDF that could be intersected by a well if the well and transfer line both had a diameter of 30.5 cm (12 in) is 0.018 m^3 (1,100 in^3). That volume is smaller than the grout volumes the DOE assumed an intruder could be exposed to in the grout-drilling scenarios, which range from 0.050 m^3 (1.8 ft^3) to 0.10 m^3 (3.5 ft^3) (see Table 4 in this TRR). Therefore, the NRC staff determined that the acute and chronic grout-drilling scenarios the DOE evaluated bound the results from drilling through a transfer line filled with grout. Decontaminated salt waste has slightly greater radionuclide concentrations than saltstone grout because the decontaminated salt waste is only one component of the grout. The 2020 SDF PA does not indicate the exact volumetric fraction of grout that is composed of decontaminated salt solution. However, the fraction can be estimated from the mass-based water-to-cement ratio of approximately 0.60 specified in the 2020 SDF PA. If approximately 40 percent of the volume of saltstone is premix and 60 percent is salt waste, the radionuclides in the decontaminated salt waste would have concentrations approximately 1.7 times greater than the radionuclides in the grout. Because the grout volumes the DOE modeled in the grout-drilling scenarios is more than a factor of two greater than the estimated volume of cuttings from drilling through a transfer line, the NRC staff determined that the grout-drilling scenario would bound the results from drilling through a transfer line filled with decontaminated salt waste.

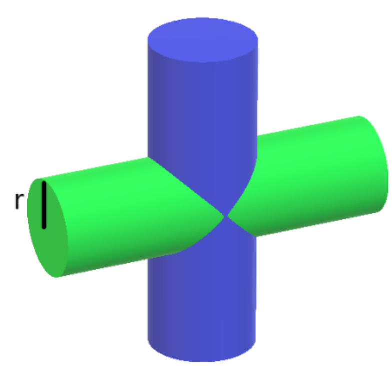

Figure 10. Diagram of a well bore intersecting a transfer line of equal radius (created by NRC staff with Microsoft Paint-3D software)

4.4 Source Term

4.4.1 Groundwater and Surface Water

The NRC staff found the modeled groundwater and surface water radionuclide concentrations to be acceptable for demonstrating compliance with 10 CFR 61.42 for two reasons: (1) they were based on models the NRC staff previously found acceptable; and (2) additional choices the DOE made to use the modeled concentrations in the intrusion analysis were conservative. The DOE calculated surface and groundwater concentrations with the Aquifer Transport Model, which the NRC staff reviewed in a TRR on hydrogeology, groundwater monitoring, and far-field modeling for the SDF (ML23017A084). The DOE used the same radionuclide concentrations in surface water for the projected dose to an offsite member of the public and an inadvertent intruder. Therefore, this section focuses on DOE selection of model outputs related to groundwater because the assumed groundwater well locations differ for an offsite member of the public and an inadvertent intruder.

The NRC staff found the DOE selection of a well location at the point with the maximum radionuclide concentration at the 1-m SDF boundary to be acceptable because the modeled radionuclide concentrations were greater on the 1-m site boundary than they were at the seven intruder well locations within the SDF (see Figure 7 above). The NRC staff found the locations of the seven intruder wells to be acceptable because the NRC staff did not identify any additional hypothetical well locations within the SDF boundary that the NRC staff expects to have greater radionuclide concentrations than the seven intruder wells. However, the NRC staff did not find all the DOE bases in Table 2 in this TRR to be justified. For example, Table 2 in this TRR indicates that the DOE chose the location for IHI Well 4 to evaluate SDS 9 and SDS 7 plume overlap. However, Figure CC-6.8 in the DOE document SRR-CWDA-2021-00072, Rev. 1, shows that the plume from SDS 9 is modeled to be in the Upper Zone of the Upper Three Runs Aquifer whereas the plume from SDS 7 is modeled to be in the lower zone of the Upper Three Runs Aquifer.

The DOE choice to use the modeled Pessimistic Case concentrations of I-129, Tc-99, and Cl-36 was conservative compared to using the Compliance Case values because it resulted in higher projected doses. The adjustment factor the DOE developed to estimate Pessimistic Case concentrations for the other radionuclide concentrations was acceptable for two reasons: (1) the DOE used the highest of the three available calculated ratios between the Pessimistic Case and Compliance Case concentrations (i.e., for I-129, Tc-99, and Cl-36); and (2) the NRC staff does not expect the contribution to dose from other radionuclides in groundwater to be risk significant.

The NRC staff also evaluated the applicability of the PORFLOW outputs the DOE chose to represent radionuclide concentrations at the 1-m well. As in the 2009 SDF PA, the DOE used the highest radionuclide concentration among grid cells that touched the 1-m SDF boundary to represent the radionuclide concentrations at the 1-m well. In the 2012 TER, the NRC described the potential for artificially large “numerical” dilution that could occur if the concentration at 1 m (3.3 ft) from the SDF boundary was significantly greater than the average in the 15 by 15 m (50 ft by 50 ft) numerical grid cells.

In a document supporting the 2009 SDF PA (SRR-CWDA-2010-00033, Rev. 1), the DOE provided an alternative analysis that bounded the potential effect of dilution by comparing radionuclide concentration from the 1-m SDF boundary near SDS 4 with radionuclide concentrations taken from directly beneath SDS 4. Because the grid cell directly below the center of SDS 4 only receives input from water flowing through the SDS, there is no dilution effect in that grid cell. That DOE analysis showed that for the 2009 SDF PA, changing the grid cell increased the projected peak dose to a chronically exposed inadvertent intruder by approximately a factor of ten (i.e., from 0.019 mSv/yr [1.9 mrem/yr] to 0.18 mSv/yr [18 mrem/yr]. In the NRC 2012 TER, the NRC indicated that the modeled radionuclide concentrations directly under the disposal structure were likely to overestimate the true concentrations at the 1-m boundary. However, in the NRC 2012 TER, the NRC also indicated that the effect might be larger for slower-moving, short-lived radionuclides because the concentration would decrease more quickly across the grid cell.

In this review of the 2020 SDF PA, the NRC staff found the DOE use of the radionuclide concentrations in the PORFLOW grid cells that touch the 1-m boundary to be acceptable for three reasons. First, in the 2020 SDF PA, the DOE reduced the grid size to one fourth the area of the grid size the DOE used in the 2009 SDF PA (i.e., vs. 58 m^2 [625 ft^2] vs. 232 m^2 [2500 ft^2]). Reducing the grid size would reduce the numerical effect of averaging concentrations over a grid cell. Second, Figure 11, below, shows that the concentration of a non-sorbing tracer does not change much over the scale of the numerical grid. That gradual change implies that the grid is fine enough that the average concentration of a mobile radionuclide like I-129 or Tc-99 in a grid cell at the edge of the SDF adequately represents the concentration at the 1-m boundary. Third, the NRC staff expects that some amount of averaging is realistic because a well at the 1-m boundary would draw in water from a region around the well (i.e., the area of effect), which would physically mix water with higher and lower radionuclide concentrations. For slower, shorter-lived radionuclides, the NRC staff expects the concentration gradient to be greater than shown in Figure 11. However, for those radionuclides the NRC staff expects the smaller grid size and real physical averaging in the well area of effect will mitigate any artificial dilution caused by averaging over the grid cells.

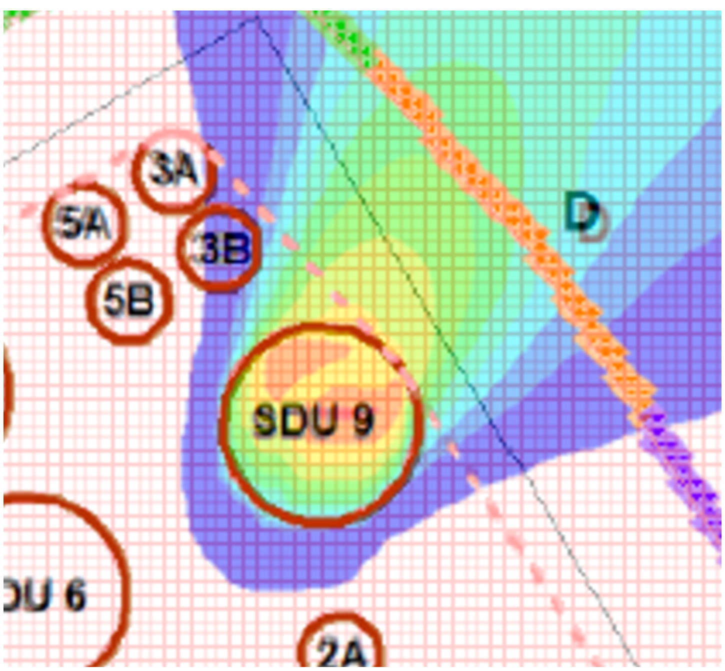

Figure 11. NRC Staff Overlay of the DOE Modeled Numerical Grid and Concentration Gradient of a Conservative Tracer in SDS 9 (Adapted From Figures 4.4-114 And 4.4-127 of the 2020 SDF PA)

4.4.2 Soil Drill Cuttings

The NRC staff found the source term the DOE used for the acute and chronic soil-drilling scenarios to be acceptable for the purpose of representing intrusion into soil near a disposal structure because they used appropriate radionuclide concentrations and cutting volumes. The NRC staff found the modeled well locations to be acceptable because the radionuclide concentrations 1 m (3.3 feet) from the SDF boundary general exceeded the concentrations at the seven locations within the SDF that the DOE selected to maximize groundwater radionuclide concentrations. The NRC staff found the radionuclide concentrations in soil the DOE originally used in the 2020 SDF PA were not acceptable because they did not account for radionuclide sorption to subsurface soil along the depth of the well bore (see Section 3.4.2 in this TRR). However, the NRC staff determined that the revised concentrations (SRR-CWDA-2021-00047, Rev. 1) were acceptable because: (1) they represented radionuclide sorption to soil; and (2) they were based on the maximum groundwater locations at any location on the 1-m boundary at any depth within 20,000 years after site closure. As described in Section 3.4.2, the DOE estimated Pessimistic Case concentrations for radionuclides other than Cl-36, I-129, and Tc-99. Although the NRC staff did not determine there is a sufficient technical basis for the factor of 7.79 the DOE used to scale the concentrations up from the Compliance Case values calculated with the Aquifer Transport Model to Pessimistic Case values, the NRC staff found the factor to be acceptable because using the factor is a conservative choice (i.e., would increase the projected dose) compared to using the Compliance Case concentrations. The NRC staff finds the Compliance Case concentrations to be acceptable because they are based on an acceptable inventory (see the NRC staff Inventory TRR [ML23017A087]) and an acceptable far-field radionuclide transport model (see the NRC staff TRR on Far-Field Modeling [ML23017A084]).

The NRC staff determined the volume of the contaminated soil drill cuttings was acceptable because a 20-cm (8-in) well diameter was consistent with local practice (ML20349G094) and the 100-foot (33-m) length was consistent with withdrawing water from the Upper Three Runs Aquifer. Although deeper wells are common near the SDF (ML20349G094), a deeper well would intersect the larger Gordon Aquifer, which the DOE expects to have more dilute radionuclide concentrations and result in lower radionuclide concentrations in the drill cuttings. For the 2020 SDF PA, the DOE conservatively assumed the entire 33 m (100 ft) well depth had the same radionuclide concentrations as the most contaminated part of the soil column.

4.4.3 Saltstone Grout Drill Cuttings

The NRC staff determined that the radionuclide source term based on drilling into saltstone grout was acceptable for use in modeling the projected dose to a chronically exposed inadvertent intruder because it accounted for the increased risk of intrusion as engineered barriers degrade, in accordance with the guidance in NUREG-2175. The NRC staff found the source term the DOE used for the chronic grout-drilling scenario to be acceptable for the purpose of representing the dose to a chronically exposed inadvertent intruder who lives on land where an individual has intruded into a disposal structure because it used an appropriate cutting volume and appropriate radionuclide concentrations. Although the NRC staff did not find the cutting volume to be appropriate for modeling acute exposure, as described further below, the NRC staff determined the result was not likely to affect the NRC staff's decision regarding compliance with the 10 CFR 61.42 PO because the projected dose to an acutely exposed individual was significantly less than the modeled dose to a chronically exposed individual.

Because the DOE considered drilling into a disposal structure to be unlikely and the DOE considered the scenario as a sensitivity analysis, the DOE used the Realistic Case inventory projection rather than the Compliance Case inventory projection as the basis for the disposal structure drill cuttings inventory. The NRC staff understood that choice as an effort to avoid compounding conservatisms. However, as described in Section 4.3, the NRC staff determined a grout-drilling scenario was plausible within 10,000 years after SDF closure. To assess the risk significance of the DOE choice, the NRC staff reviewed the ratio of the Compliance Case inventory to the Realistic Case inventory based on Table 1 in the NRC TRR on the SDF Inventory (ML23017A087). In that TRR, the NRC staff found the Compliance Case inventories, which the DOE also referred to as the "Most Probable and Defensible" inventories to be acceptable for use in the intrusion analysis.

Although the NRC staff did not make a separate determination that the Realistic Case inventories, which the DOE also referred to as the "Best Estimate" inventories, were acceptable for use in the intrusion analysis, in the review for this TRR the NRC staff determined the inventories were acceptable for use in the intrusion analysis because there is a relatively small difference between the Realistic Case and Compliance Case inventories for key radionuclides. Specifically, for the chronically exposed individual, the most risk significant radionuclides are Tc-99 and I-129. For Tc-99, the Best Estimate inventory is 4 percent smaller than the Compliance Case projection for I-129 and for Tc-99 it is 32 percent smaller. For acute exposure, in the 2020 SDF PA the DOE projected that Pu-239, Sn-126, Pu-240, and Am-241 would make the greatest contributions to dose from acute exposure. The Best Estimate inventory projections for those radionuclides were all 31 percent or 32 percent smaller than the Compliance Case values. The NRC staff expects that the intrusion dose projections will be linearly related to dose, which allows the NRC staff to determine projected doses for the Compliance Case inventory. As discussed further in Section 4.6 in this TRR, the projected doses in the intrusion analysis are all sufficiently less than the dose limit that a 31percent increase would not change the NRC determination about compliance with the 10 CFR 61.42 PO.

As indicated in Section 3.4.3, the DOE assumed a driller would use different methods to drill into SRS soil or a disposal structure. Specifically, the DOE assumed a driller would use mud rotary drilling to drill into SRS soil but would switch to a coring bit once the driller encountered increased resistance from a disposal structure. That assumption has a significant effect on the projected dose because it affects the modeled volume of drill cuttings brought to the surface (see Table 4, above). The NRC staff found the assumption that a driller would use a coring bit to drill through a disposal structure to be acceptable because it is consistent with current practice of well drillers near the SDF when encountering an unusually hard drilling material (ML20349G094). Furthermore, the NRC staff found the resulting grout cutting volume to be acceptable for modeling chronic exposure because, when a driller uses a coring bit, only the part of the grout in the annular region of the bit would be pulverized and spread on the land surface.

In contrast, the NRC staff did not find the volume to be applicable to modeling the dose to an acutely exposed individual because a well driller would be exposed to the intact part of the core prior to disposal. Although the NRC staff expects an intact core to provide self-shielding, which would limit the effect of the larger inventory in the drill core compared to the annular region, the self-shielding may not eliminate the effect of the larger inventory in the intact core. That intact core would contribute to the dose from direct exposure for an acutely exposed individual. In the 2020 SDF PA, the DOE projected that incidental ingestion and direct exposure were the top two exposure pathways, accounting for approximately 70 percent and 20 percent of the peak dose, respectively. The large margin between the DOE projected dose for an acutely exposed in advertent intruder (i.e., 0.026 mSv [2.6 mrem]) and the applicable dose limit (i.e., 5 mSv

[500 mrem]) makes it unlikely that adding direct exposure from the intact core would change the compliance demonstration. However, the NRC staff determined that excluding exposure to the core is inconsistent with the DOE exposure scenario for intrusion into a disposal structure, which the NRC staff considers to be a plausible exposure scenario. Therefore:

> ***INTA-02*** *The NRC staff recommends monitoring the development of information related to the dose from external exposure in the acute grout-drilling scenario (i.e., the dose to a well driller from external exposure to grout after drilling into a disposal structure) under a new low-priority monitoring factor entitled "Intrusion Source Terms" under the new monitoring area entitled "Inadvertent Intrusion."*

4.4.4 Concentrations in Garden Soil

The NRC staff found the DOE conceptual model in which garden soil could be contaminated by both radionuclide build up and by being mixed with drill cuttings to be acceptable because it represented the major sources of soil contamination. The NRC staff found the DOE calculation method of summing dose contributions from soil contaminated with each source rather than combining sources to calculate one set of radionuclide concentrations in soil to be acceptable because the method is mathematically equivalent to assuming the inventories add linearly. Conceptually, that assumption is similar to assuming the model represents the dose shortly after intrusion occurs, before soil concentrations of radionuclides have an opportunity to re-equilibrate with the radionuclides in concentrations in irrigation water. That DOE choice is conservative because it represents the maximum contribution from both contamination sources.

The NRC staff previously reviewed the DOE calculation of radionuclide concentrations in soil due to radionuclide buildup from contaminated irrigation water in a separate TRR on the DOE Dose and Exposure Pathways Model (ML23017A113). Therefore, the remainder of this section addresses the modeled radionuclide concentrations in soil mixed with drill cuttings.

The NRC staff found the DOE calculation of radionuclide concentrations in garden soil mixed with drill cuttings to be acceptable for modeling doses to a chronically exposed individual for two reasons: (1) the NRC staff found the drill cutting inventories to be acceptable; and (2) independent NRC analyses, described in the following paragraph, demonstrated that reasonable changes in the garden area, which affects the averaging volume, did not have a significant effect on the projected dose. However, the NRC staff did not find the DOE assumption of a minimum garden size of 100 m^2 (1080 ft^2) to be adequately supported for either soil drill cuttings or grout drill cuttings. As discussed in Section 3.4.4 of this TRR, for a chronically exposed inadvertent intruder, decreasing the modeled garden area increases the projected dose by increasing the modeled radionuclide concentrations in garden soil. For soil drill cuttings, the DOE calculations indicated a reasonable minimum of 33 m^2 (1080 ft^2). For grout drill cuttings, the DOE did not provide a basis for the minimum garden size; however, the basis the DOE provided for the mixing volume for soil drill cuttings was based on the drill cuttings volume, which is much smaller for the grout drill cuttings.

To evaluate the effect of using a smaller garden size on the projected dose to a chronically exposed inadvertent intruder, the NRC staff used the GoldSim model files the DOE provided in response to the NRC staff's first set of RAI questions to conduct deterministic sensitivity analyses with smaller garden sizes. In that model, the DOE fraction of locally consumed produce accounted for changes in the garden size. That is, when the model uses a smaller garden size, it also projects a smaller fraction of produce grown locally. The NRC staff previously reviewed the modeled relationship between garden size and the fraction of local produce in a TRR on the DOE Dose and Exposure Pathways Model (ML23017A113) and found the relationship to be acceptable.

To test the effect of changing the garden size in the soil drill cuttings scenario, the NRC staff tested a 33 m^2 (360 ft^2) garden area, per the DOE calculation described in Section 3.4.4 in this TRR. Using the DOE model, that change had a negligible effect on the projected peak dose to a chronically exposed inadvertent intruder. Furthermore, the change slightly decreased the projected peak dose within 10,000 years from 0.022 mSv/yr (2.2 mrem/yr) to 0.021 mSv/yr (2.1 mrem/yr).

In contrast, the NRC staff found decreasing the modeled garden size significantly increased the projected dose in the grout-drilling scenario. For the grout-drilling scenario, the DOE analysis of the minimum garden size, which the DOE based on the volume of the drill cuttings, would not apply. Therefore, to test the effect of using a smaller garden size on the projected dose to a chronically exposed inadvertent intruder, the NRC staff tested a minimum garden size of 16 m^2 (170 ft^2) which the NRC staff previously calculated as a reasonable minimum garden size in an NRC 2016 TRR on the DOE Biosphere model (ML16277A060). Making the same change to the garden size in a grout-drilling scenario based on drilling through SDS 7 changed the peak projected dose within 10,000 years from 1.7 mSv/yr (170 mrem/yr) to 2.8 mSv/yr (280 mrem/yr). The NRC staff determined that the DOE probabilistic sensitivity analysis did not identify model sensitivity to the garden area in a grout-drilling scenario for two reasons: (1) the DOE probabilistic analysis only considered the soil-drilling scenario; and (2) the DOE analysis used a minimum garden area of 100 m^2 (1,080 ft^2).

The different effects of reducing the garden size in the soil-drilling and grout-drilling scenarios appear to result from a difference in the dominant sources of contamination. For the soil-drilling scenario, a significant fraction of the soil contamination results from radionuclide buildup from contaminated irrigation water, which is independent of garden size. Therefore, decreasing the garden size would decrease the projected dose by reducing the calculated fraction of local produce. In contrast, for the grout-drilling scenario, the dominant source of contamination in garden soil is mixing with drill cuttings. Therefore, the main effect of reducing the garden size is to increase the radionuclide concentrations in garden soil.

Because the NRC determinations about the concentration of radionuclides in garden soil due to mixing with drill cuttings were based on the results of sensitivity analyses rather than the DOE bases for those parameter values, the findings in this TRR apply only to the 2020 SDF PA. Specifically, the NRC finding that the radionuclide concentrations in garden soils due to the contribution from mixing with soil drill cuttings are based on the small effect of reasonable changes to the garden size. Similarly, the NRC staff interest in the radionuclide concentrations in garden soil due to mixing with grout drill cuttings are based on the more significant effects of changing the modeled garden size on the projected dose to a chronically exposed inadvertent intruder in the grout-drilling scenario. The NRC staff determined that: (1) the DOE basis for establishing a minimum garden size of 100 m^2 (1,080 ft^2) in the 2020 SDF PA was based on the volume of soil drill cuttings rather than the much smaller volume of grout drill cuttings; and (2) reasonable changes to the garden size significantly affect the projected dose to a chronically exposed inadvertent intruder in the grout-drilling scenario. Therefore:

> ***INTA-03*** *The NRC staff recommends monitoring the development of information about the volume of soil that grout drill cuttings could be mixed with under the new monitoring factor entitled "Intrusion Source Terms," which the NRC staff recommended opening in INTA-01 under the new monitoring area entitled "Inadvertent Intrusion."*

4.5 Exposure Pathways

In general, the NRC staff found the exposure pathways that the DOE modeled for the acutely and chronically exposed inadvertent intruder to be acceptable because they represented the primary foreseeable pathways for an individual to be exposed to radioactivity from the SDF. The following subsections note minor exceptions and indicate areas the NRC staff will monitor related to exposure pathways for an inadvertent intruder.

4.5.1 Acute Exposure Pathways

The NRC staff determined that the exposure pathways the DOE modeled in the inadvertent intrusion analysis for an acutely exposed inadvertent intruder in the 2020 SDF PA were acceptable for assessing the projected dose to an individual who had a short-term exposure to radioactivity at the SDF because they included foreseeable pathways of direct contact with the waste or contaminated environmental media. In general, the DOE modeled fewer exposure pathways for an acutely exposed inadvertent intruder than for a chronically exposed inadvertent intruder, which is consistent with the NRC guidance in NUREG-2175. As discussed in Section 4.3 in this TRR, the NRC staff found well drilling to be an acceptable exposure scenario for acute exposures at the SDF. Most of the parameters that affect the potential dose to an acutely exposed inadvertent intruder also affect the dose to a chronically exposed inadvertent intruder (see Section 4.5.2 in this TRR). This section focuses on parameters specific to the acutely exposed inadvertent intruder exposure pathways (i.e., well drilling).

In the 2020 SDF PA, the modeled drilling time affects all three exposure pathways for an acutely exposed inadvertent intruder (i.e., direct exposure, suspended soil inhalation, inadvertent ingestion of soil). The NRC staff found the DOE projected exposure time of 20 h to be consistent with the NRC guidance in NUREG-2175, which indicates well installation can be modeled with a duration that is “typically less than a day.” The NRC staff found the use of the drilling time to model the direct exposure pathway to be acceptable because it logically represents the exposure. In contrast, the NRC staff did not find the DOE use of the exposure duration to scale the annual average incidental soil ingestion rate to be adequately justified because the annual rate is unlikely to represent the increased soil contact expected during well drilling activities. However, as discussed in further detail in the NRC staff TRR on the Dose and Exposure Pathways Model (ML23017A113), the incidental soil ingestion rate the DOE chose was sufficiently conservative that the NRC staff expects reasonable changes to the rate would not significantly increase the projected dose. Similarly, the NRC staff did not find the DOE use of the chronic exposure time to scale the annual inhalation rate to be representative of the critical group because the annual average includes significant time resting or sleeping, which is not reflective of well drilling activities. The NRC staff previously addressed the representativeness of an annual inhalation rate to various exposure pathways in a TRR on the DOE Dose and Exposure Pathways Model (ML23017A113). That TRR includes a recommendation to modify the NRC SDF Monitoring Plan with a new monitoring factor under both 10 CFR 61.41 and 10 CFR 61.42.

The NRC staff did not find the soil mass loading the DOE used to represent soil inhalation while drilling (i.e., 1×10^{-4} g/m^3 [6.2×10^{-9} lb/ft^3]) to be adequately supported for projecting the dose to an acutely exposed inadvertent intruder because the technical basis the DOE provided applied to ambient “non-urban” conditions rather than to ground-disrupting activities like well drilling. The NRC guidance document NUREG/CR-5512, Vol. 3, “Residual Radioactive Contamination From Decommissioning Parameter Analysis,” (ML082460902) provides a recommended value of

5 x 10^{-4} g/m^3 (3.1 x 10^{-8} lb/ft^3) for gardening and does not provide a value for well drilling. The NRC guidance document NUREG/CR-4370, Vol. 1, "Update of Part 61 Impacts Analysis Methodology," (ML100251399) used a range of values from 2.6 x 10^{-4} g/m^3 [1.6 x 10^{-8} lb/ft^3] to 7.4 x 10^{-3} g/m^3 (4.6 x 10^{-7} lb/ft^3) to represent dust loading during construction activities. Changing the air mass loading during drilling from 1 x 10^{-4} g/m^3 (6.2 x 10^{-9} lb/ft^3) to 7.4 x 10^{-3} g/m^3 (4.6 x 10^{-7} lb/ft^3) increased the projected peak dose for an acutely exposed inadvertent intruder who drills into SDS 7 from 0.026 mSv (2.6 mrem) to 0.23 mSv (23 mrem). Although that value was significantly less than the dose limit of 5 mSv (500 mrem), the relative change was large (i.e., greater than a factor of 10). The risk significance of that effect could increase with changes to the model that increased the projected dose to an acutely exposed inadvertent intruder (e.g., an increase in long-lived alpha-emitting radionuclides). In addition, the NRC staff found that the use of an air mass loading factor for gardening was inconsistent with the critical group for the acutely exposed inadvertent intruder (i.e., well drillers). Therefore:

> ***INTA-04*** *The NRC staff recommends that the staff monitor the DOE basis for the mass loading factor for contaminated drill cuttings in air during drilling activities under a new medium-priority monitoring factor entitled "Intrusion Exposure Pathways" under the new monitoring area entitled, "Inadvertent Intrusion."*

4.5.2 Chronic Exposure Pathways

The NRC staff determined that the chronic exposure pathways the DOE modeled in the inadvertent intrusion analysis in the 2020 SDF PA were acceptable for assessing compliance with the 10 CFR 61.42 PO because they reflected the main foreseeable ways an individual could be exposed to radiation from the SDF. In the intrusion analysis, the DOE used the same pathways that the DOE included for an offsite member of the public, which the NRC staff reviewed in a TRR on the DOE Dose and Exposure Pathways Model (ML23017A113). For that reason, the NRC staff's recommendations in that TRR for modifying the NRC SDF Monitoring Plan also apply to this TRR.

In addition, the NRC staff found two unexpected differences between the DOE modeling of the projected dose to a chronically exposed inadvertent intruder and the dose to an offsite member of the public.

First, in the 2020 SDF PA, the DOE indicated that it intended to model inhalation and direct exposure of an inadvertent intruder to radionuclides in garden soil for the modeled gardening time. However, in the implementation of the Dose and Exposure Pathways Model for the chronically exposed inadvertent intruder, the DOE used the parameter "FractionDrilling" for the dose contribution from inhaling suspended soil contaminated by mixing with drill cuttings (see Figure 12 below) for the chronically exposed inadvertent intruder. The NRC staff expected that parameter to be "FractionInGarden," to reflect that a chronically exposed inadvertent intruder could inhale suspended soil during the time gardening. Because the deterministic value of the fraction of the year gardening is significantly greater than the deterministic value of the fraction of the year drilling (i.e., 1,900 h/yr versus 20 h/yr), using the fraction of the time gardening would increase the projected dose to a chronically exposed inadvertent intruder.

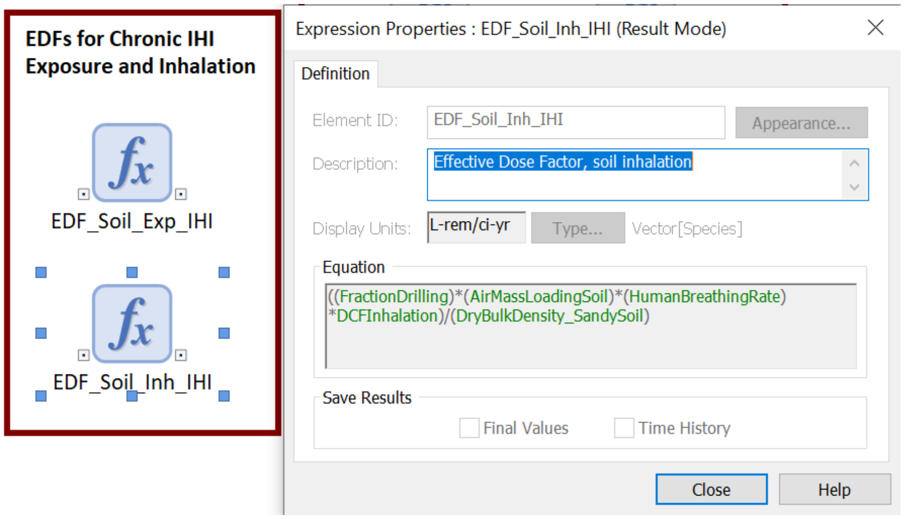

Figure 12. Function Representing Chronic Inhalation of Suspended Garden Soil in the DOE Model *SRS Saltstone V5.051_PF_Casecv.8_SL_Ratio_IHI_SDU7_Drill*

To assess the risk significance of using the fraction of time gardening instead of the fraction of time drilling, the NRC staff used the intrusion models the DOE provided with the DOE document SRR-CWDA-2021-00047, Rev. 1, to conduct an independent analysis. The NRC staff found that changing the input for the exposure time for inhalation had an insignificant effect on the projected peak dose to a chronically exposed inadvertent intruder in the grout-drilling scenario (i.e., it increased the peak projected dose from 1.70 mSv/yr [170 mrem/yr] to 1.72 mSv/yr [172 mrem/yr]). The change had a minimal effect on dose because plant ingestion dominated exposures for a chronically exposed inadvertent intruder (i.e., 87 percent of the projected peak dose), followed by inadvertent soil ingestion (i.e., 6.6 percent of the projected dose). Therefore, although increasing the exposure time increased the dose contribution from inhalation of suspended soil by approximately a factor of 10, it had a minimal effect on the total projected peak dose.

Second, as described in Section 3.5.2 in this TRR, the DOE excluded the dose from radionuclides volatilizing from saltstone from the intrusion analysis on the basis that the projected dose to an offsite member of the public was negligible. In contrast with exposures to contaminated soil and saltstone grout, the NRC staff found the found the DOE decision not to model the dose to an individual living onsite from volatilized radionuclides was not well supported. As described in Section 3.5.1 in this TRR, the DOE decided not to model that exposure because the dose to an offsite member of the public from radionuclides that volatilize out of saltstone grout was negligible. The NRC staff determined that the DOE basis was inadequate because the radionuclide concentrations in air in a dwelling constructed above a disposal structure would be greater than the radionuclide concentrations in air at the boundary of the SDF due to radionuclide dispersion that would occur between the air above the disposal structure and the SDF boundary.

Although the NRC staff did not find the DOE decision to exclude volatilized radionuclides from the intrusion analysis to be adequately supported, the NRC staff expects the dose to an individual who lives in a home above a disposal structure would not be risk significant based on previous DOE analyses and NRC staff determinations. Specifically, the DOE evaluated projected dose to an individual in a dwelling constructed above a disposal structure in the 2009 SDF PA and the NRC staff found that evaluation to be acceptable in the NRC 2012 TER. Although the 2009 SDF PA and 2020 SDF PA use different inventories and disposal structure assumptions, the projected dose to an individual who lives in a dwelling above a disposal structure was sufficiently low in the 2009 SDF PA (i.e., 3 x 10^{-8} mSv/yr [3 x 10^{-6} mrem/yr]) that the NRC staff does not expect the updated assumptions in the 2020 SDF PA to produce a risk significant dose projection.

4.6 Deterministic Dose Projections

The NRC staff found the collection of dose projections the DOE provided in the 2020 SDF PA and DOE document SRR-CWDA-2021-00047, Rev. 1 to be acceptable for comparison with the dose limits of the 10 CFR 61.42 PO for three reasons: (1) the projected doses represented a sufficient range of reasonably foreseeable exposure scenarios; (2) the implementation of the scenarios in the intrusion model reflected reasonable assumptions, with minor exceptions as described in other sections of this TRR; and (3) the implementation of the dose projections was sufficiently transparent that the NRC staff could readily evaluate the risk significance of changes to parameter values or model assumptions.

Table 8, below, provides the deterministic model outputs from key scenarios in the 2020 SDF PA and DOE Responses to the NRC RAI questions. In general, those results show that chronic exposure scenarios yielded greater projected doses than acute exposure scenarios and exposure to grout drill cuttings yielded greater projected doses than drilling into contaminated soil. As indicated in Section 4.3 in this TRR, the NRC staff found drilling into a disposal structure to be a reasonably foreseeable exposure scenario because of the long half-lives of the key radionuclides and the potential for disposal structure degradation and technology changes within 10,000 years of SDF closure.

Table 8. Projected Dose in DOE Inadvertent Intrusion Analyses

Exposure Scenario	Projected Peak Dose within 10,000 Years of SDF Closure	Reference
Acute exposure to soil drill cuttings	3.5 x 10^{-6} mSv/yr	SRR-CWDA-2021-00047, Rev. 1
Chronic exposure to soil drill cuttings and groundwater	0.035 mSv/yr	SRR-CWDA-2021-00047, Rev. 1
Acute exposure to grout drill cuttings	0.026 mSv	2020 SDF PA
Chronic exposure to grout drill cuttings	1.7 mSv	2020 SDF PA

As described in Section 3.6 in this TRR, the DOE analyses showed that the plant ingestion pathway dominated chronic exposure to both soil and grout drill cuttings. For acute exposures, incidental ingestion of soil dominated the exposure to both soil and grout drill cuttings in the DOE analysis. However, as described in Section 4.5.1 in this TRR, reasonable changes to the soil loading in air could significantly increase the projected dose and make inhalation the dominant dose pathway in the grout drill cuttings scenario. As indicated in that section, the NRC staff identified the technical basis for the mass loading during drilling as technical issue for further monitoring.

As described in Section 3.6 in this TRR, the DOE analyses showed that Tc-99 and I-129 dominated the projected doses to both the acutely and chronically exposed inadvertent intruder in the soil-drilling scenarios. In addition, the DOE analyses showed that Tc-99 and Pu-239 accounted for almost all the projected dose for the chronically exposed inadvertent intruder in the grout-drilling case. In contrast, for acute exposure to grout drill cuttings, Pu-239, Sn-126, Pu-240, and Am-241 all contributed significantly to the projected dose. As shown in a previous TRR on Inventory for the 2020 SDF PA (ML23017A087), the NRC staff found the DOE methods for developing the inventory for those radionuclides in the 2020 SDF PA to be acceptable. As shown in that TRR, the DOE Pessimistic Case estimate of the inventory of each of those radionuclides is approximately 60 percent greater than the DOE Realistic Case estimate of those radionuclides. The NRC staff expects the projected dose from those radionuclides for the chronically exposed inadvertent intruder in the grout-drilling scenario would scale approximately linearly with the inventory because the inventory directly affects the concentration of the radionuclides in saltstone grout. Therefore, the NRC staff expects the projected dose to the chronically exposed inadvertent intruder in the grout-drilling scenario would be approximately 2.7 mSv/yr (270 mrem/yr) if the DOE used the pessimistic inventory of those radionuclides.

4.7 Deterministic Sensitivity Analyses

The NRC staff found the set of deterministic sensitivity analyses the DOE conducted for the intrusion analysis to be acceptable for the purpose of providing risk insights for the 2020 SDF PA because the analyses covered reasonably foreseeable sources of uncertainty. The deterministic analyses addressed model uncertainties that could not be addressed easily by varying parameter values in the probabilistic sensitivity analysis. Specifically, the DOE used the deterministic sensitivity analyses to address the nature of the source term (i.e., soil or grout), the time of intrusion, biosphere uncertainties in Central Scenario Cases, and the effects of human intrusion into a disposal structure on SDF performance.

The DOE analyses demonstrated that the largest source of uncertainty for the intrusion analysis was the conceptual model uncertainty of whether an individual could intrude into saltstone grout. In that analysis, the DOE made a key assumption that an individual who drills into a disposal structure would use a coring drill bit, which reduced the modeled volume of drill cuttings brought to the surface by a factor of 10 or more compared to a rotary drilling technique (see Table 4 in this TRR). As indicated in Section 4.4.3 in this TRR, the NRC staff found the assumption that a driller would use a coring bit to be acceptable because it is consistent with current practice of well drillers near the SRS when encountering an especially hard drilling material (ML20349G094). The resulting peak projected dose for a chronically exposed inadvertent intruder in the grout-drilling scenario (i.e., 1.7 mSv/yr [170 mrem/yr]) was significantly greater than the Compliance Case peak projected dose for a chronically exposed inadvertent intruder in the soil-drilling scenario after the inventory adjustment to account for radionuclide sorption to soil (i.e., 0.032 mSv/yr [3.2 mrem/yr]). However, the projected dose in the grout-drilling scenario was significantly less than the 5 mSv/yr (500 mrem/yr) dose limit.

The results of the remaining DOE sensitivity analyses demonstrated that the next largest source of uncertainty is the combination of parameter values the DOE grouped together as alternative Central Scenario Cases (i.e., Realistic Case, Pessimistic Case). The DOE analysis showed the Pessimistic Case analysis for the chronically exposed inadvertent intruder in a soil-drilling scenario had a peak projected dose within 10,000 years of closure that was approximately a factor of 29 greater than the Realistic Case projection. As shown in Figure 8 in this TRR, the resulting Pessimistic Case doses remained significantly less than the 5 mSv/yr (500 mrem/yr) dose limit. The NRC staff expects that the same factor of 29 increase between the Realistic and Pessimistic Cases is not applicable to the grout-drilling scenarios because the NRC staff expects that most of the variation in the soil-drilling scenario results from varying assumptions that affect the SDF hydraulic performance and those assumptions are not applicable to a grout-drilling scenario in which an intruder comes into direct contact with the wasteform rather than radionuclides transported by groundwater.

The final two DOE sensitivity analyses demonstrated that the DOE does not expect invertebrate intrusion into the SDF or human intrusion into a disposal structure to have a significant effect on the peak projected dose to an acutely exposed inadvertent intruder or a chronically exposed inadvertent intruder. The NRC staff agrees with the DOE assessment of invertebrate intrusion because the erosion barrier should limit animal intrusion into the SDF and the quantities of waste invertebrates could bring to the surface are limited. The NRC staff also agrees with the DOE assessment that human intrusion into a disposal structure would have a minimal effect on system performance because a well-constructed well should not allow significant water flow along its length. The NRC staff further reviewed that scenario in a separate TRR on percolation through and potential erosion near the Closure Cap (ML23017A083).

4.8 Probabilistic Sensitivity and Uncertainty Analyses

4.8.1 *Stochastic Parameter Distributions*

The NRC staff found most of the stochastic parameter distributions the DOE used in the intrusion analysis to be acceptable for the purpose of providing risk insights for the 2020 SDF PA because the distributions represented sufficient ranges to show the effects on model projections. For most parameters for which the DOE did not implement ranges in the intrusion analysis (e.g., till depth, well depth) the NRC staff expects that either: (1) the deterministic choice is conservative; or (2) reasonable changes in the parameter values would not significantly change the projected dose to an inadvertent intruder.

One exception to that NRC assessment is the mass loading of drill cuttings in the air during drilling, which the NRC staff addressed in Section 4.5.1 of this TRR. The DOE probabilistic analysis did not identify the sensitivity of the projected dose to the mass loading of drill cuttings in air because the DOE did not represent the parameter with a stochastic distribution in in the probabilistic sensitivity analysis. As described in Section 4.5.1 in this TRR, the NRC staff recommends a change to the NRC monitoring plan to track that issue.

A second exception, as indicated in Section 4.5.2 in this TRR, was that the DOE did not provide a reason that the probabilistic SDF GoldSim model included the uncertainty in the till depth for the leach rate and excluded it from the calculation for the radionuclide concentrations in garden soil. In the 2020 SDF PA, the deterministic value the DOE used for the tilling depth (i.e. 0.15 m [6 in]) was the minimum value of the distribution. In some models, increasing the modeled tilling depth can increase the projected dose by exposing more of the modeled plant roots to contaminated soil. However, the DOE did not represent root depth in the model. Instead, the DOE assumed the root uptake of a radionuclide into a plant was proportional to the concentration in the soil, regardless of the depth of the contamination and the depth of the plant roots. Therefore, the NRC staff expects that the only effect of increasing the modeled tilling depth would be to decrease the modeled radionuclide concentrations in the garden soil and, thereby, to decrease the projected dose.

4.8.2 *Probabilistic Sensitivity Analysis*

In general, the NRC staff found the probabilistic sensitivity analysis in the 2020 SDF PA acceptable for identifying the most risk significant parameters affecting the dose to a chronically exposed inadvertent intruder in a soil-drilling scenario because it reflected the largest uncertainties in that intrusion exposure scenario. However, the NRC staff found that the exclusion of other intrusion exposure scenarios and source terms limited the risk insights that the DOE could gain from the analysis.

The NRC staff found the DOE decision to base the analysis on the dose to a chronically exposed inadvertent intruder rather than acutely exposed inadvertent intruder to be acceptable because the DOE analysis projected larger doses for a chronically exposed individual. However, limiting the analysis to that intrusion exposure scenario is likely to cause the DOE to underestimate the risk significance of parameters that only affect the acutely exposed inadvertent intruder (e.g., solids loading in air during drilling). The NRC staff did not identify that omission as an immediate concern because the projected dose to an acutely exposed inadvertent intruder is significantly less than the 5 mSv/yr [500 mrem/yr] dose limit, even in the grout-drilling scenario. However, modeling only chronic exposures is a limitation of the probabilistic sensitivity analysis.

Because the radionuclides that dominate the dose to an acutely exposed inadvertent intruder in the grout-drilling scenario differ from the radionuclides that dominate the dose in almost all other intrusion exposure scenarios, including the dose to an acutely exposed inadvertent intruder in a grout-drilling scenario is likely to allow the DOE to have different risk insights than the analysis in the 2020 SDF PA (e.g., insights related to different exposure pathways and radionuclides).

Similarly, the NRC staff found the DOE choice to conduct a probabilistic sensitivity analysis only for a soil-drilling scenario and to exclude the grout-drilling scenario from the probabilistic analysis significantly limited the risk insights the DOE could gain from the probabilistic analysis. The NRC staff expects the most significant difference between probabilistic analyses for the two source terms would be the relative importance of parameters related to water flow through saltstone. As described further below, the probabilistic sensitivity analysis based on the soil-drilling scenario identified parameters related to water flow as the most risk significant parameters in the intrusion analysis. That result is consistent with the key assumption of the soil-drilling scenario, in which radionuclides must first be transported out of the saltstone wasteform in water to reach an inadvertent intruder. A probability analysis of the grout-drilling scenario would allow the DOE to identify parameters that are important to the intrusion analysis independent of water flow because the radionuclides do not need to be transported out of saltstone to reach the inadvertent intruder in that intrusion exposure scenario.

Like the probabilistic analysis for an offsite member of the public, the probabilistic analysis identified several parameters related to water flow as having the greatest effect on the projected dose to a chronically exposed inadvertent intruder in the soil-drilling scenario: infiltration, saltstone hydraulic conductivity, and saltstone degradation. The NRC staff reviewed those parameters in separate TRRs related to percolation through and potential erosion near the Closure Cap (ML23017A083) and Near-Field Flow (ML23017A086). Of the parameters identified as having the most risk significance in the probability sensitivity analysis for the intrusion analysis, none were related specifically to intrusion. That result is consistent with the DOE using the same exposure pathways and the same biosphere model, with small changes in implementation, for both an offsite member of the public and a chronically exposed inadvertent intruder. The DOE identified model risk significant model assumptions that were specific to the intrusion analysis, such as the modeled source term, in deterministic sensitivity analyses (see Sections 3.7 and 4.7 in this TRR).

The NRC staff expects that the DOE probabilistic analysis overstates the importance of the modeled till depth by including the uncertainty in the till depth in the calculation of the leach rate and excluding it from the calculation of the radionuclide concentrations in soil because the NRC staff expects the two relationships would mitigate each other to some extent. Specifically, the DOE found that including the till depth in the calculation of the leach rate increased the projected dose with increasing till depth (see Figure 9 in this TRR). In contrast, including the till depth in the calculation of the radionuclide concentrations in soil would reduce the projected dose by reducing radionuclide concentrations. However, because the till depth is an assumption about a future individual's behavior, the NRC staff did not identify a practical engineering implication or a needed monitoring activity associated with parameter.

The NRC staff expects the results of the probabilistic sensitivity analysis would remain valid after the DOE revised the soil drill cuttings inventory because the inventory revision did not change the dominant radionuclides or exposure pathways for the chronically exposed inadvertent intruder in the soil-drilling scenario.

4.8.2 *Probabilistic Uncertainty Analysis*

The NRC staff found the probabilistic uncertainty analysis in the 2020 SDF PA to be acceptable for providing risk insights for the projected dose to a chronically exposed inadvertent intruder in a soil-drilling scenario because it reflected the largest uncertainties in the main exposure pathways in that intrusion exposure scenario. The NRC staff found the DOE decision to exclude the dose to an acutely exposed individual from the probabilistic uncertainty analysis to be acceptable because the DOE deterministic analysis demonstrated that a chronically exposed individual is likely to receive a larger dose than an acutely exposed individual. Therefore, the NRC staff expects that the range of results the DOE found for a chronically exposed individual would bound the range of doses the DOE would find for an acutely exposed individual.

In contrast, the NRC staff found the DOE choice to exclude the grout-drilling scenario from the probabilistic analysis limited the utility of the probabilistic analysis because: (1) the soil-drilling scenario does not bound the projected doses from the grout-drilling scenario; and (2) the NRC staff expects that drilling into a disposal structure is plausible after the disposal structure roofs degrade. Therefore, the NRC staff was limited to insights from the deterministic sensitivity analyses and deterministic grout-drilling scenario analysis to evaluate the potential dose results from that intrusion exposure scenario.

Although the DOE revision of the soil drill cutting inventory to reflect sorption to soil would affect the range of dose projections in the DOE probabilistic uncertainty analysis, the NRC staff does not expect the change in inventory to significantly affect the 10 CFR 61.42 PO compliance determination because the change in inventory is too small to increase the projected doses to values close to the dose limit. The DOE document SRR-CWDA-20121-00047, Rev. 1 showed an increase in the deterministic projection from approximately 0.02 mSv/yr (2 mrem/yr) to approximately 0.03 mSv/yr (3 mrem/yr) (see Figure 4 in this TRR). Therefore, the NRC staff expects that the revised soil drill cuttings inventory could increase the probabilistic dose results by approximately 50 percent. Using 3,000 stochastic realizations, the DOE calculated the peak of the mean dose within 10,000 years of site closure to be 0.069 mSv/yr (6.9 mrem/yr). The peak within 20,000 years of site closure was similar (i.e., 0.070 mSv/yr [7.0 mrem/yr]). The DOE calculated the peak of the 95th percentile result to be 0.21 mSv/yr (21 mrem/yr) within 10,000 years of site closure and 0.22 mSv/yr (22 mrem/yr) within 20,000 years of closure. Therefore, accounting for a potential increase in dose based on the revised inventory in soil drill cuttings, the NRC staff expects the peak of the mean dose projection for a chronically exposed inadvertent intruder in the soil-drilling scenario to be significantly less than the 5 mSv/yr (500 mrem/yr) dose limit.

5.0 Teleconference or Meeting

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

6.0 Follow-up Actions

Except for NRC staff recommendations to revise the NRC SDF Monitoring Plan, there are no specific Follow-up Actions related to this TRR.

7.0 Conclusions

The NRC staff determined that the set of intrusion analyses in the 2020 SDF PA, as amended by the DOE responses to NRC RAI questions, are acceptable for modeling the projected dose from the SDF for the purpose of the DOE demonstrating compliance with the 10 CFR 61.42 PO (Protection of Individuals from Inadvertent Intrusion) because, collectively, the intrusion analyses represented the main sources of radioactivity, intrusion exposure scenarios, and exposure pathways. In addition, the NRC staff determined The NRC staff disagreed with the DOE determination that the grout-drilling scenario was an implausible inadvertent intrusion exposure scenario because: (1) the dominant radionuclides the DOE identified in its intrusion analyses have very long half-lives compared to the 10,000 year performance period the NRC staff uses to assess compliance with the 10 CFR 61.42 PO (NUREG-1854; ML072360184); (2) the disposal structures and grout could degrade significantly within 10,000 years of site closure; and (3) a survey of well drillers near the SRS indicated that a well driller is likely to persist if a client supports additional work and methods are available (e.g., drilling with a coring bit) to accomplish the job (ML20349G094). However, the NRC staff determined that the DOE analysis of the grout-drilling scenario as an alternative analysis provided sufficient information for the NRC staff to use in its evaluation of compliance with the 10 CFR 61.21 PO.

The NRC staff determined that, collectively, the deterministic and probabilistic sensitivity analyses were acceptable for providing risk insights into the key model assumptions because they represented key sources of uncertainty in a chronic intrusion exposure scenario. However, the NRC staff found that the exclusion of acute intrusion exposure scenarios and the grout-drilling scenario from probabilistic analyses limited the risk insights that those analyses could provide. Similarly, the NRC staff found that the DOE probabilistic uncertainty analysis provided useful risk insights, although it was limited by excluding the grout-drilling scenario.

As indicated in Section 4.5.2 in this TRR, the NRC staff recommended changes to the NRC SDF Monitoring Plan in a TRR on the DOE Dose and Exposure Pathways Model (ML23017A113) that apply to both an offsite member of the public and an inadvertent intruder. However, in this TRR, the NRC staff made recommended changes to the NRC SDF Monitoring Plan that only affect NRC monitoring under the 10 CFR 61.42 PO (Protection of Individuals from Inadvertent Intrusion). Therefore, for clarity:

> ***INTA-01*** *The NRC staff recommends opening a new monitoring area entitled “Inadvertent Intrusion” related primarily to the protection of individuals from inadvertent intrusion under the 10 CFR 61.42 Performance Objective.*

Based on the review documented in this TRR, the NRC staff also made the following three recommendations to add monitoring factors to the new monitoring area:

INTA-02 *The NRC staff recommends monitoring the development of information related to the dose from external exposure in the acute grout-drilling scenario (i.e., the dose to a well driller from external exposure to grout after drilling into a disposal structure) under a new low-priority monitoring factor entitled "Intrusion Source Terms" under the new monitoring area entitled "Inadvertent Intrusion."*

INTA-03 *The NRC staff recommends monitoring the development of information about the volume of soil that grout drill cuttings could be mixed with under the new monitoring factor entitled "Intrusion Source Terms," which the NRC staff recommended opening in INTA-01 under the new monitoring area entitled "Inadvertent Intrusion."*

INTA-04 *The NRC staff recommends that the staff monitor the DOE basis for the mass loading factor for contaminated drill cuttings in air during drilling activities under a new medium-priority monitoring factor entitled "Intrusion Exposure Pathways" under the new monitoring area entitled, "Inadvertent Intrusion."*

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