NRC Consultation and Monitoring at the Savannah River Site: Focusing Reviews of Two Different Disposal Actions – 12181

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ABSTRACT

Section 3116 of the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005 (NDAA) requires the U.S. Department of Energy (DOE) to consult with the U.S. Nuclear Regulatory Commission (NRC) for certain non-high level waste determinations. The NDAA also requires NRC to monitor DOE's disposal actions related to those determinations. In Fiscal Year 2011, the NRC staff reviewed DOE performance assessments for tank closure at the F-Tank Farm (FTF) Facility and salt waste disposal at the Saltstone Disposal Facility (SDF) at the Savannah River Site (SRS) as part of consultation and monitoring, respectively. Differences in inventories, waste forms, and key barriers led to different areas of focus in the NRC reviews of these two activities at the SRS. Because of the key role of chemically reducing grouts in both applications, the evaluation of chemical barriers was significant to both reviews. However, radionuclide solubility in precipitated metal oxides is expected to play a significant role in FTF performance whereas release of several key radionuclides from the SDF is controlled by sorption or precipitation within the cementitious wasteform itself. Similarly, both reviews included an evaluation of physical barriers to flow, but differences in the physical configurations of the waste led to differences in the reviews. For example, NRC's review of the FTF focused on the modeled degradation of carbon steel tank liners while the staff's review of the SDF performance included a detailed evaluation of the physical degradation of the saltstone wasteform and infiltration-limiting closure cap. Because of the long time periods considered (i.e., tens of thousands of years), the NRC reviews of both facilities included detailed evaluation of the engineered chemical and physical barriers.

INTRODUCTION

First cycle reprocessing waste is high-level waste based on its origin[1]. The U.S. Nuclear Regulatory Commission (NRC) recognizes that although some wastes originating from reprocessing must be treated and disposed of as high-level waste, other waste, called "waste incidental to reprocessing" (WIR) does not require geologic disposal to manage the risks it poses. The U.S. Department of Energy (DOE) uses a process called a "waste determination" to determine whether certain wastes resulting from reprocessing are high-level waste or WIR. Section 3116 of the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005 (NDAA) requires the DOE to consult with the U.S. Nuclear Regulatory Commission (NRC) for certain non-high-level waste determinations. The NDAA also requires NRC to monitor DOE's disposal actions related to those determinations. In Fiscal Year (FY) 2011, the NRC staff reviewed a DOE waste determination with supporting performance assessment (PA) for closure of the F-Tank Farm (FTF) at the Savannah River Site (SRS) and an updated PA for salt waste

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[1] The Atomic Energy Act of 1954 (at 40 U.S. Code 10101 (12)) defines High Level Waste as the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and (B) other highly radioactive material that the [U.S. Nuclear Regulatory] Commission, consistent with existing law, determines by rule requires permanent isolation.

disposal at the Saltstone Disposal Facility (SDF) at SRS, for which DOE completed a waste determination in 2006.

The SRS is a 780 square kilometer (300 square mile) site located in western South Carolina and owned by the U.S. Department of Energy (DOE). The site began operation in 1951 and has produced nuclear material for national defense, research, medical, and space programs. Significant quantities of high-level radioactive waste are currently stored on site in large underground waste storage tanks, which DOE is in the process of closing. The SRS has 51 underground waste storage tanks located at two tank farms. The FTF covers approximately 8.9 hectares (22 acres) and contains 22 tanks, two of which have been filled with stabilizing grout and closed. FTF closure entails removing liquid waste, solid salt waste, and precipitated sludge from waste tanks to the maximum extent practical and stabilizing the residual waste by filling the tanks with a reducing grout. Waste remaining in the tanks at closure will be residual sludge concentrated along the floor and, to a lesser extent, the walls of the tanks.

The liquefied salt waste that results from tank cleaning is solidified with dry components to form a cementitious waste form called saltstone that is disposed of at the SDF. Because the liquid waste is well mixed with cementitious materials to form the final waste form, the radioactivity in the SDF will be more evenly distributed than the radioactivity remaining in the FTF (Fig. 1). Waste disposal at the SDF began in 1990 with Vault 1 and continues today with disposal into Vault 4. DOE plans to complete salt waste disposal and close the SDF in 2030.

PROCEDURAL CONSIDERATIONS

The NDAA specifies three criteria for determining whether waste is WIR: (1) the waste does not require disposal in a geologic repository, (2) the waste has had “highly radioactive radionuclides” (HRRs) removed to the maximum extent practical, and (3) disposal will meet the performance objectives outlined in 10 CFR Part 61 Subpart C for land disposal of radioactive waste. NRC reviews compliance with these criteria when reviewing a waste determination, which occurs during the consultation phase. During the subsequent monitoring phase, the NRC staff considers only the third criterion: whether disposal will meet the performance objectives of 10 CFR Part 61. These performance objectives include provisions for protection of members of the general population from releases of radioactivity, protection of individuals from inadvertent intrusion, and protection of workers, as well as a requirement for site stability.

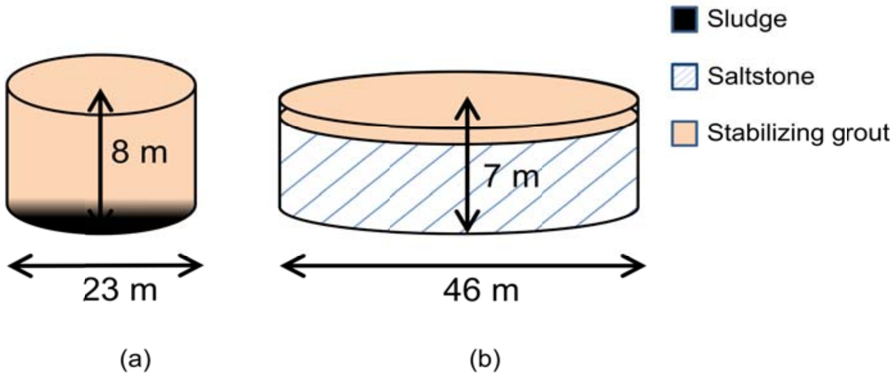

Fig. 1. Abstraction of radioactivity in (a) an FTF tank and (b) an SDF future disposal unit (FDC). Radioactivity in the tank is primarily concentrated in the sludge layer at the bottom and, to a lesser extent, the sides of the tank. Radioactivity in the FDC is distributed throughout the saltstone waste form (figure not to scale).

As part of consultation regarding the FTF, NRC participated in several technical meetings with the South Carolina Department of Health and Environmental Control (SCDHEC), the U.S. Environmental Protection Agency (EPA), and DOE. The purpose of the meetings was to ensure that all parties understood all underlying assumptions, parameter values and modeling results that DOE intended to use in its assessment. As a result of these meetings, DOE issued a preliminary FTF PA for NRC, EPA, and SCDHEC review and comment in June 2008 [1]. DOE followed the preliminary FTF PA with a final draft of the FTF PA in March 2010 [2]. In July 2010, DOE, NRC, SCDHEC, and EPA participated in a public scoping meeting in Aiken, South Carolina. At this meeting, members of the public were invited to comment on the assumptions and analyses to be used to develop the draft FTF waste determination [3]. DOE considered this feedback and published a Draft Waste Determination for the FTF in September 2010 [4].

The consultation phase for salt waste disposal at the SDF began shortly after the passage of the NDAA and culminated in the NRC staff's initial Technical Evaluation Report (TER) [5] and SDF monitoring plan [6]. In its 2005 review, the NRC staff concluded that the salt waste did not require disposal in a geologic repository (Criterion 1) and that highly radioactive radionuclides would be removed to the maximum extent practical (Criterion 2). The NRC staff also concluded that it had reasonable assurance that salt waste disposal at the SDF would meet the performance objectives of 10 CFR Part 61 provided certain assumptions in DOE's analyses were verified during monitoring (Criterion 3). The staff identified factors important to assessing compliance with 10 CFR 61, Subpart C, including improvements in future modeling and the necessary associated model support. The staff's concern was that some of the assumptions made in the analysis, if incorrect, could lead to noncompliance with the performance objectives. Since that time, the NRC staff has monitored disposal actions and changes in disposal plans at the SDF with periodic monitoring trips [7-11] and with technical reviews of research designed to support assessment of the long-term performance of the SDF [12-15].

In November 2009, DOE submitted an updated PA for salt waste disposal that it created as part of its PA maintenance program [16]. The NRC staff is reviewing the revised PA as part of its monitoring activities under the NDAA and will document its review in a TER. The revised PA accounts for additional information collected since NRC's initial review as well as changes in DOE's disposal plans. For example, the initial review considered disposal in approximately 16 large vaults similar to Vaults 1 and 4 while the review conducted in FY 2011 considers disposal of salt waste in 64 smaller cylindrical FDCs in addition to Vaults 1 and 4.

Because the FTF review was part of consultation, one of the significant products of the FTF review was a series of technical recommendations for DOE's consideration included in the TER [17]. Recommendations developed by the NRC staff during consultation do not require a response from DOE. However, recommendations may indicate areas that will be monitored by NRC staff after the site enters the monitoring phase. The SDF TER, completed under monitoring, does not include recommendations. Technical concerns developed by the NRC staff during monitoring either are resolved in the short term through communication with DOE staff or, if they require a longer-term response, are tracked as open issues or action items.

TECHNICAL CONSIDERATIONS

Modeling Approach

DOE modeled long-term performance of both the FTF and SDF with a "hybrid" of a deterministic and probabilistic approach. In both cases, the hybrid approach includes a deterministic base case, several deterministic sensitivity cases, and a probabilistic assessment. The probabilistic assessments, implemented in the GoldSim® modeling platform, rely on some of the output from the deterministic models. For example, one-dimensional near-field flow rates through the grouted systems used in the probabilistic modeling cases are abstracted from two-dimensional, deterministic PORFLOW models for the corresponding deterministic cases.

The combination of a deterministic base case, deterministic sensitivity cases, and a probabilistic model could allow DOE to consider different types of uncertainty and sensitivity information. In the PAs for both the FTF and SDF, the deterministic base cases, which DOE described as the expected conditions, were used with deterministic sensitivity cases to explore the importance of various model assumptions. For example, in the FTF PA, DOE used deterministic sensitivity cases to evaluate the sensitivity of the PA results to inventory, basemat K_d values, and natural system K_d values. Additionally, DOE performed a comprehensive barrier analysis to study the influence of near-field modeling assumptions on overall system performance for FTF.
In the SDF review, deterministic sensitivity cases were used to evaluate the impact of the closure cap and assumptions about fracture development in the saltstone waste form.

However, because deterministic near-field flow results are "hard wired" into the probabilistic models, the probabilistic models could not provide information about the relative importance of assumptions and parameters affecting modeled flow and near field release, which the NRC staff expects to have a significant effect on modeled performance for both systems. The NRC staff's use of DOE's probabilistic model was further limited in the SDF review because the model relied on base case flow values that the NRC staff believes to be optimistic [18]. Although near-field flow rates are only varied by Configuration or Case in the probabilistic assessment for FTF, ultimately, the flow rates through the grouted system generally approach the long-term, steady-state infiltration rate predicted for the site for each Configuration modeled for FTF. Thus, the limited consideration of uncertainty in the near-field flow rates is less of an issue for FTF.

In both PAs, DOE conducted a multi-step model adjustment process, referred to as benchmarking. During benchmarking, DOE modified the GoldSim® model to optimize the match of intermediate GoldSim® model results (i.e., flux into the saturated zone and peak groundwater concentrations at 100 meters [m] from the SDF) with the results of the deterministic model. GoldSim® model components adjusted during benchmarking of the FTF PA include cell size or number of cells used to simulate a flow path, Darcy velocity, a benchmarking factor applied with the plume function factor to reflect the effect of transverse dispersion, and clay fraction. Values adjusted in the SDF PA included a pseudo-K_d for Tc-99, far field effects of a flow divide, contributions from certain individual disposal units at the point of compliance, and flow though various system components including the aquifer zone, vault floors, vault walls, and saltstone grout. In both reviews, NRC staff asked for additional information about the benchmarking process [19, 20]. For the FTF, probabilistic modeling results appear to yield significantly higher peak doses than the results of similar deterministic simulations following the benchmarking process. NRC staff noted that the pattern may indicate systematic biases in either model for the FTF. For the SDF, the relationship of the deterministic and probabilistic results varied by scenario and radionuclide.

Site Conceptual Models

The base case FTF and SDF systems both rely on engineered barriers to significantly delay and attenuate radionuclide release. In the FTF base case, DOE indicated it expects release to be significantly delayed by the steel tank liners and chemical conditioning of infiltrating water by the reducing grout. DOE expects peak doses from the key radionuclides Pu-239, Np-237, and Tc-99 to be significantly attenuated by (1) solubility control of Pu-239 and Np-237 (and, in some cases, Tc-99) by chemical barriers in the contaminated zone and tank grout; (2) the concrete basemats underneath the tanks, which mitigate the release of Tc-99, Pu-239 and Np-237; (3) natural system dilution and dispersion for Tc-99, Pu-239, and Np-237; and (4) Pu-239 sorption in the subsurface. Each of these barriers reduces the magnitude of releases or concentrations along flow paths away from FTF sources by orders of magnitude.

In response to an NRC staff Request for Additional Information (RAI) on FTF [19], DOE performed “Case G” analyses to study a potential conceptual model referred to as Condition 2 in DOE’s PA [2]. In Condition 2, a fast flow path exists through the tank grout prior to significant (bulk) grout degradation. Therefore, flow through the system is dominated by fractures or cracks that might form in the system over time (e.g., shrinkage gaps, or cracks that might develop due to thermal or mechanical stresses imposed on the system during curing, or due to corrosion of steel components) and waste release is dominated by water that has not been chemically conditioned by prolonged contact with the reducing grout. Because the Case G scenario defeats the chemical barrier provided by the reducing grout early in a 10,000 year performance period[2], the likelihood of Case G is particularly important to DOE’s compliance demonstration.

For FTF, NRC staff also is concerned with an alternative scenario in which the water table rises above the bottom of the tanks (or the tank bottoms are within the zone of water table fluctuation), leading to accelerated corrosion and direct contact of saturated groundwater with the contaminated zone. Because Type IV tanks (1) have bottoms located at or near the elevation of the long-term average water table, (2) have no vault annulus to grout, (3) have experienced groundwater in-leakage into tank vaults, and (4) contain a risk-significant inventory of Pu-239 (e.g., Tank 18), the likelihood of early, unconditioned release of tank waste due to water table rise is of particular concern for Type IV tanks. Thus, in its TER for FTF, the NRC staff recommended DOE perform experiments to evaluate radionuclide solubility under a range of chemical conditions relevant to the residual sludge in the grouted waste tanks. If DOE can show dissolved concentrations of key radionuclides can be limited to non-risk-significant levels under all relevant chemical conditions, the conceptual model for waste release (and the timing of the release) becomes less important.

In DOE’s base case for the SDF, radionuclide release is limited principally by the nearly complete hydraulic isolation of saltstone by the site infiltration cap, engineered layers above the disposal cell roofs, and the hydraulic performance of the saltstone itself. Although chemically reducing conditions are important to Tc-99 solubility and sorption, the base case DOE model allows such a small flow of water through the waste form that chemically oxidizing conditions do

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[2] The “NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations, Draft Final Report for Interim Use” (NUREG-1854) recommends “Generally, a period of 10,000 years after closure is sufficient to capture the peak dose from the more mobile, long-lived radionuclides and to demonstrate the influence of the natural and engineered systems in achieving the performance objectives (NRC, 2000). However, assessments beyond 10,000 years may be necessary to ensure (1) that the disposal of certain types of waste does not result in markedly high impacts to future generations or (2) evaluate waste disposal at arid sites with extremely long groundwater travel times. Periods of performance shorter than 10,000 years are generally not appropriate for disposal facilities for incidental waste, because of the larger fraction of long-lived radionuclides compared to a typical commercial low-level waste (LLW) disposal facility. Presenting and understanding long-term risk (e.g., greater than 10,000 years) can be an important part of performance assessment analyses, even if those risks are not used to demonstrate compliance with the performance objectives of 10 CFR Part 61, Subpart C.”

not significantly affect predicted Tc release [16]. For example, in DOE's base case for the SDF, at 8000 years less than 0.2% of natural infiltration is predicted to flow into Vault 4. In the SDF review, the NRC staff disagreed with DOE's determination that the base case (Case A) represents the expected, or most probable, case. As described in the second NRC RAI [18], the NRC staff believes DOE's SDF base case is unrealistic and non-conservative. Two of the principal concerns are that (1) the base case is inconsistent with known site conditions and (2) it does not account for the observed range of experimentally measured values representing saltstone and vault initial conditions, or potential temporal evolution of conditions. For example, in the base case, saltstone is predicted to remain unfractured for the entire simulation period (i.e., 20,000 years) [21] even though fracturing of saltstone has been observed [22] and saltstone fracturing has been predicted elsewhere by DOE [23]. Similarly, the DOE base case assumes the hydraulic conductivity of saltstone is representative of laboratory-prepared samples, even though core samples of field-emplaced saltstone have been shown to have roughly two orders of magnitude greater hydraulic conductivity [24].

In response to these and other NRC concerns [18], DOE developed the "Case K" analysis [25]. The main differences between the SDF base case and Case K analyses are (1) inclusion of saltstone fracturing with time, (2) removal of suspect moisture characteristic curves with the assumption that the relatively permeability is always 1, (3) increasing saltstone hydraulic conductivity with time, (4) lower assumed saltstone reducing capacity, (5) increased vault degradation with time, (6) updated K_d values in cementitious materials, (7) updated inventories of Ra-226 and its ancestors, and (8) updated biosphere parameters. Because it reflects the effects of saltstone fracturing and hydraulic degradation, as well as other modifications to the base case assumptions, the NRC staff relied on Case K heavily in its review.

Because more water is predicted to flow through saltstone in Case K than in DOE's base case for the SDF, the chemical barrier to Tc release provided by the chemically reducing environment in saltstone is more risk-significant in Case K than it is in the SDF base case. Because chemical oxidation of saltstone is expected to proceed from fractures in contact with infiltrating water or air, and Tc release is sensitive to saltstone oxidation, Case K results are sensitive to the assumed rate and degree of saltstone fracturing. Because more radionuclide release is predicted to occur in Case K than in the DOE base case for the SDF, and because the vaults are modeled with greater Tc K_d values than the saltstone in Case K, Tc reconcentration in and re-release from the vaults significantly affects Case K results. Thus in the SDF review, the NRC staff emphasized the review of predicted saltstone fracturing and the chemical barriers created by the saltstone and the vaults.

Inventory and Key Radionuclides

Both the FTF and SDF are expected to have significant inventories of long-lived radionuclides (Table I). For several radionuclides significant to dose, the final inventories disposed of in the FTF and SDF are expected to be similar (i.e., inventory ratios similar to 1 in Figure 2). Two notable exceptions are the long-lived radionuclides Tc-99 and I-129, which have much smaller projected inventories in the FTF as compared to the SDF. Technetium-99 and I-129 are expected to have relatively higher inventories in the SDF than the FTF because they are primarily associated with salt waste that is more easily removed from the tanks than sludge. In addition, they are difficult to remove from the liquid salt waste, and therefore are primarily disposed of in saltstone instead of having a significant fraction removed during salt waste treatment for disposal in glass, as certain other very soluble radionuclides do (e.g., Cs-137).

Table I DOE predicted inventories and concentrations of select radionuclides in the F-Tank Farm Residuals and Saltstone Disposal Facility at closure.

Radionuclide	Half Life (years)	Projected Residual Radionuclide Inventory in the FTF at Closure	Projected Radionuclide Inventory in the SDF at Closure	Projected Residual Radionuclide Concentrations in FTF Tank 18 at Closure	Projected Radionuclide Concentrations in SDF Vault 4 at Closure
		(GBq)[a, b]	(GBq) [a, c]	(Bq/g) [a, d]	(Bq/g) [a, e]
Tc-99	$2.11 \cdot 10^5$	$2.48 \cdot 10^4$	$1.30 \cdot 10^6$	$1.67 \cdot 10^2$	$7.77 \cdot 10^0$
I-129	$1.57 \cdot 10^7$	$7.40 \cdot 10^{-1}$	$9.25 \cdot 10^2$	$4.81 \cdot 10^{-2}$	$5.92 \cdot 10^{-3}$
Cs-137	$3.00 \cdot 10^1$	$5.03 \cdot 10^6$	$1.11 \cdot 10^7$	$1.41 \cdot 10^6$	$4.81 \cdot 10^3$
U-234	$2.46 \cdot 10^5$	$7.88 \cdot 10^1$	$1.30 \cdot 10^3$	$5.18 \cdot 10^1$	$7.77 \cdot 10^{-2}$
Np-237	$2.14 \cdot 10^6$	$8.14 \cdot 10^1$	$1.41 \cdot 10^2$	$2.59 \cdot 10^1$	$4.44 \cdot 10^{-3}$
Pu-239	$2.41 \cdot 10^4$	$2.41 \cdot 10^4$	$4.81 \cdot 10^4$	$4.81 \cdot 10^4$	$9.62 \cdot 10^{-1}$

[a] One Curie (Ci) is equal to $3.7 \cdot 10^{10}$ Becquerel (Bq).

[b] Inventories reflect projected values for the entire FTF at closure (from [17] Table 3-2).

[c] Inventories reflect projected values for the entire SDF at closure (from [16] Table 3.3-7).

[d] The reporting units for Tank 18 radionuclide species analytical concentrations are presented per gram of solids after air drying and homogenization [26].

[e] Vault 4 concentrations are based on the inventory disposed as of 9/30/10 [27], the total volume of saltstone disposed as of 9/30/10 [28], and the dry density of saltstone reported in the DOE 2009 PA for the SDF [16] (i.e., 1.01 g/cm3).

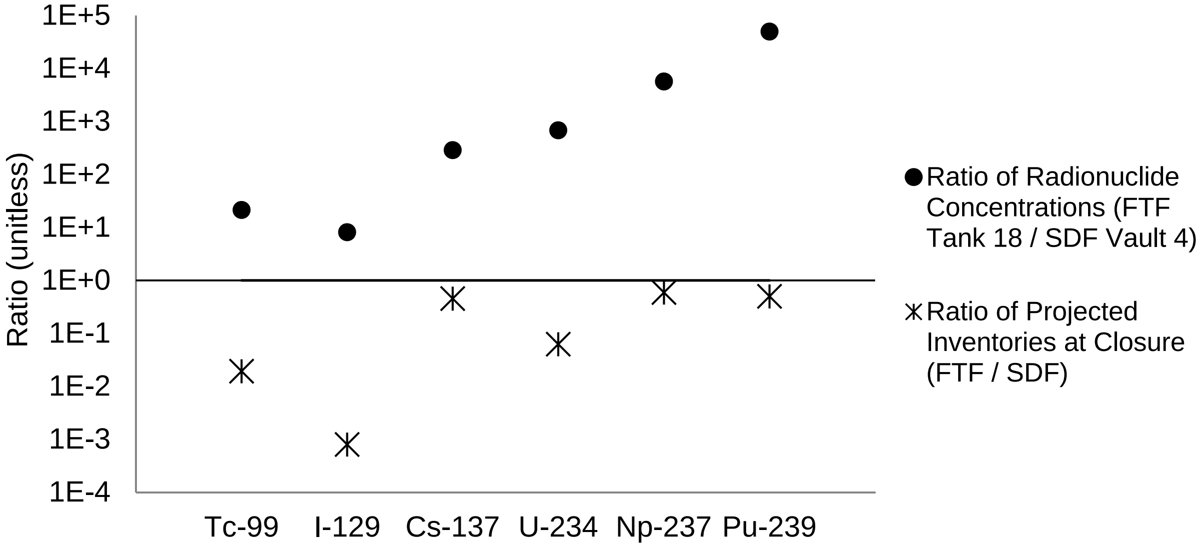

Fig. 2. A comparison of the inventories and concentrations of selected key radionuclides in the FTF and SDF. Inventory ratios reflect the projected inventories of residual waste in the entire FTF and SDF at closure as represented in the NRC FTF TER [17] and DOE SDF PA [16]. Concentration ratios represent the ratio of FTF Tank 18 sludge to the projected concentrations in SDF Vault 4 (Table I).

Notwithstanding the larger inventory of I-129 and Tc-99 in the SDF, in general, key radionuclides are expected to be more concentrated in the FTF sludge than in saltstone. Although FTF and SDF total inventories are similar for several key radionuclides, FTF waste is assumed to be concentrated primarily in approximately 220 cubic m (59,000 gallons)[3] of residual sludge primarily occurring in thin layers at the bottoms of the 22 waste tanks, whereas the SDF inventory is expected to be distributed over approximately $7.6 \cdot 10^5$ cubic meters (200 million gallons) of solidified saltstone. In particular, the concentrations of several key radionuclides are significantly greater for Tank 18 at FTF than they are expected to be in SDF Vault 4 at the time of closure (i.e., concentration ratios greater than 1 in Figure 2). Tank 18 and Vault 4 were chosen for comparison in Figure 2 because they currently are among the best characterized units in each disposal facility, and because Tank 18 and Vault 4 are risk-significant units in their respective disposal facilities.

The NRC staff regards the NDAA term “highly radioactive radionuclides” (HRRs) as describing those radionuclides that pose the greatest risk to off-site members of the public, workers, and individuals who may inadvertently intrude on the site. In general, the NRC staff does not make a distinction between HRRs and key radionuclides. In the FTF review, DOE identified ten radionuclides as HRRs: Sr-90, Tc-99, I-129, Cs-137, U-234, Np-237, Pu-238, Pu-239, Pu-240, and Am-241. Considering uncertainty in the dose predictions, DOE identified all of the HRRs, with the exception of Sr-90 and Cs-137, as important to the 10 CFR 61.41 evaluation of protection of the general population, while Sr-90, Cs-137, Np-237, and Am-241 were listed as HRRs based on the 10 CFR 61.42 evaluation for protection of individuals from inadvertent intrusion. In the FTF review, the NRC staff reviewed DOE’s approach to developing the HRR list and found it to be generally acceptable

In the 2005 waste determination for the SDF, DOE identified Cs-137 (and its daughter, Ba-137m), Sr-90 (and its daughter, Y-90), Pu-238, Am-241, Cm-244, Pu-239, Se- 79, I-129, and Tc-99 as HRRs based on predicted doses to off-site members of the public, a potential inadvertent intruder, and workers. In the 2009 PA, DOE identified Ra-226, Tc-99, I-129, Np-237, and Pa-231 as key radionuclides because they caused a dose greater than $5 \cdot 10^{-4}$ milliSievert per year (mSv/yr) (0.05 millirem per year [mrem/yr]) to an off-site member of the public in DOE’s base case. Based on DOE’s 2009 PA for SDF, the NRC staff identified Ra-226, Tc-99, and I-129 as the primary dose drivers for an off-site member of the public under various scenarios. Although the initial DOE PA for the SDF predicted Ra-226 to be the radionuclide most significant to the dose to an offsite member of the public, revisions to the inventory made in response to NRC’s second RAI [22] reduced the inventory of Ra-226 and its ancestors, Pu-238, U-234, and Th-230, such that the peak dose to an offsite member of the public in 10,000 years was attributable to I-129 and the peak dose in 20,000 years was attributable to Tc-99 [22].

Time of Peak Dose

DOE predicted peak doses from the FTF to occur later than peak doses from the SDF. For the FTF, 99.9 percent of the realizations in DOE’s probabilistic model[4] have peak doses that occur

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[3] Estimated residual sludge volume in the FTF is based on an estimated residual volume of approximately 34 cubic meters (9000 gallons) in Tanks 17-20 and an estimated residual of 0.015 m (0.6 inches) of sludge in the 18 remaining 22.5 to 26 m (75 to 85 ft) diameter tanks. DOE expects to leave only a 0.0015 meter (0.06 inch) layer of sludge in the remaining tanks but 0.015 meters (0.6 inches) was used in the volume calculation as DOE assumed a factor 10 increase in inventory estimates for conservatism.

[4] Probabilistic results are provided for the FTF “All Cases” model, which includes all the alternative conceptual models except Case G, which was modeled following PA development in response to RAIs.

Table II DOE projected doses to off-site members of the public due to residual waste in the F-Tank Farm and Saltstone Disposal Facility based on the DOE deterministic base cases and selected sensitivity cases.

	Peak Dose in 10,000 years (mSv/yr)	Time of peak dose in 10,000 years (year)	Peak Dose in 20,000 years (mSv/yr)	Time of peak dose in 20,000 years (year)
FTF DOE Base Case [a]	0.023	10,000	0.18	17,000
FTF Case G [a]	1.3[b]	10,000	5.5	20,000
SDF DOE Base Case (Case A) [a]	0.014	10,000	0.031	15,000[b]
SDF Case K [a]	0.088	8,700[b]	0.55[a]	15,000

[a] Doses to “off-site” members of the public represent the dose 100 m from the disposal facility.
[b] Values rounded to two significant digits

beyond 10,000 years and 97.5 percent after 20,000 years. With its deterministic model for the FTF, DOE estimated peak doses to an off-site member of the public from the FTF facility may reach approximately 6 mSv/yr (600 mrem/yr) at 27,000 years (Table II). The peak of the mean dose in the “All Cases” probabilistic analysis is reported to be approximately 3.5 mSv/yr (350 mrem/yr) at 38,000 years; however, due to risk dilution (i.e., spreading of peak doses over time) the mean of the peaks dose is calculated to be approximately 20 mSv/yr (2000 mrem/yr) with an average time of 36,000 years.

In the SDF base case, doses from key radionuclides appear to remain fairly stable at approximately 0.03 to 0.04 mSv/yr (3 to 4 mrem/yr) between 20,000 and 40,000 years[5]. However, the magnitude and time of the predicted peak dose are not clear because DOE’s deterministic model runs beyond 20,000 years only included radionuclides that made significant dose contributions at 100 m (330 feet) from the site within 20,000 years and, therefore, may have excluded slower-moving radionuclides[6] [22]. In DOE’s base case, the predicted peak dose within 20,000 years is a 0.031 mSv/yr (3.1 mrem/yr) peak dose attributable primarily to I-129 and Ra-226 that occurs at approximately 15,000 years [16]. In SDF Case K, the predicted peak dose from Tc-99 is 0.55 mSv/yr (55 mrem/yr) and occurs at approximately 15,000 years [22]. In a related case, called K1, modeled with slightly lower and better-supported saltstone K_d values[7] the peak dose from Tc-99 increases to 0.90 mSv/yr (90 mrem/yr) and advances to approximately 13,000 years.

Because DOE expects the peak doses from both the FTF and SDF to occur after 10,000 years, in both reviews the NRC staff considered modeled physical and chemical barriers that affected the timing of the projected peak dose to an off-site member of the public. In the case of the

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[5] Predicted doses of hundreds of millirem at very long time frames (hundreds of thousands of years) reported in the SDF PA [16] appear to be attributable to an error in DOE’s probabilistic model.

[6] Long-term probabilistic runs included the full set of relevant radionuclides, but because of both structural issues discussed earlier and apparent errors in DOE’s probabilistic model for the SDF, NRC could not use those results for estimates of peak dose.

[7] Case K1 uses a Tc K_d value of 500 mL/g in reducing grout and 0.8 mL/g in oxidizing grout. Case K uses a Tc K_d value of 1000 mL/g in reducing grout and 10 mL/g in oxidizing grout.

FTF, several key modeling assumptions in DOE's PA serve to delay radionuclide releases for thousands to tens of thousands of years. Alternative configurations indicate that if key modeling assumptions prove to be invalid (e.g., if the reducing grout is bypassed or chemical transitions occur faster than assumed in the PA), the peak doses could occur within a 10,000 year performance period. For the SDF, peak Tc-99 doses in Case K and K1 are notably smaller than the predicted peak dose from the FTF. However, the predicted SDF peak doses in Cases K and K1 also could indicate the potential for unacceptable doses during a 10,000 year performance period if certain key assumptions about the timing of saltstone fracturing and the retention of Tc-99 in disposal unit walls and floors are incorrect.

Barriers to Flow

Differences in the primary barriers to flow caused one of the main differences in technical focus between the two reviews. The barrier to flow most significantly delaying the predicted dose from the FTF is the steel tank liner. Because of the importance of the carbon steel liners in delaying the release of radioactivity from the FTF tanks (in most cases delaying releases to times beyond a 10,000 year period of performance) and the limited amount of information available to validate steel liner corrosion modeling, the NRC staff developed several RAI comments in this area during the FTF review [19]. While DOE considered a variety of potential corrosion mechanisms and conditions, modeling results suggest that, in most cases, the stabilized concrete vaults surrounding the steel liners continue to provide a passive environment leading to low corrosion rates similar to the initial general corrosion rate of 0.001 millimeters per year [0.04 mils per year] for thousands to tens of thousands of years. This result is due in large part to DOE assumptions regarding the ability of the concrete vault to limit water flow and diffusion of deleterious species into the tank vaults over long time periods. Multiple observations of groundwater in-leakage into tank vaults, as well as cracking, trenching, scarifying, and patching of concrete vaults suggest that assumptions regarding the integrity of the concrete vaults may be overly optimistic, as may assumptions regarding the long-term performance of the steel liners.

The as-modeled barriers to flow most significantly delaying the predicted dose from the SDF are (1) the diversion of infiltrating water around the vaults due to the contrast in the hydraulic conductivities of the lower drainage layer and the roof and (2) the physical integrity of the saltstone grout. For the FDCs, flow also is significantly limited by a composite high-density polyethelene (HDPE) geosynthetic clay liner (GCL) layer above the roofs. Because of the importance of the physical integrity of the saltstone grout, a significant number of NRC's RAI comments focused on representation of saltstone degradation mechanisms, predicted development of fractures in the grout, and the moisture characteristic curves used to model unsaturated flow through the monolith [18, 20]. DOE's Case K analysis, developed in response to NRC's RAIs, represents saltstone fracturing as increases in saltstone hydraulic conductivity and diffusivity. Because modeled crack frequency increases logarithmically, a significant fraction of cracking occurs late in a 10,000 year performance period. Case K also responds to the RAI on moisture characteristic curves used in DOE's base case by assuming a fixed relative permeability of 1.

Chemical Barriers

Chemical barriers in the FTF assessment contribute to a delay in the peak dose for tens of thousands of years. Thus, NRC staff focused on assumptions related to chemical barrier performance in its review. In the FTF, the presence of mineral phases in the residual waste sludge significantly limits aqueous phase concentrations of HRRs. Dose drivers, such as Tc-99, Pu-239 and Np-237, are believed to be solubility-limited in the sludge, either as oxides/hydroxides (Np) or co-precipitated as trace elements (Tc and Pu) with iron phases in the waste sludge. Upon transition to a more oxidizing environment, Tc solubility is assumed to be lower, rather than higher, because the solubility of Tc is tied to the solubility of the iron phases with which it is assumed to be associated. NRC staff is concerned that if a significant fraction of Tc is not co-precipitated with iron, then the release of Tc could occur much earlier than predicted in DOE's base case analysis and potentially within a 10,000 year period of performance.

Because radioactivity in the FTF is contained primarily in residual sludge in the bottom of the waste tanks, whereas radioactivity in the SDF is spread throughout the grout wasteform, chemical conditioning and release mechanisms differ. In the FTF model, chemical conditioning of incoming water is achieved by water flowing through the grout used to fill the emptied waste tanks before it hits the residual waste. Because the concentrated sludge in the FTF tanks is not well-mixed with the grout, a potential exists for infiltrating groundwater to by-pass the tank grout, which could lead to higher concentrations of key radionuclides being leached from the tanks earlier in the performance period. As stated previously in the case of Type IV tanks at FTF that are at or in close proximity to the average long-term water table, a potential also exists for saturated groundwater in-leakage into the tank vaults, accelerated corrosion, and unconditioned release of key radionuclides from the tank system into the water table aquifer. The conceptual model for flow through the tank system can, therefore, have a significant effect on the magnitude of the peak dose predicted to occur within a 10,000 year performance period. In the SDF, chemical conditioning is achieved by the grout wasteform itself, so the NRC review did not evaluate analogous conditions in which water bypasses the chemical conditioning of the grout.

For the SDF, the principal chemical barriers are high pH and chemically reducing conditions (i.e., low Eh) in the saltstone grout. In particular, the completeness of the initial reduction of Tc by saltstone grout and the duration of reducing conditions was originally cited as a risk significant issue in the 2005 review of the SDF disposal plans and is currently an Open Issue (Open Issue 2009-1) in SDF monitoring. In both the FTF and SDF reviews, the NRC staff cited a lack of model support for the projected evolution of chemical conditions in waste as a significant source of uncertainty in the long-term performance of the disposal facilities [17, 18, 20].

Far-field Considerations

The geometry of SDF and FTF sources in relation to groundwater flow also impacts risk from each facility. Major FTF sources include 22 waste tanks representing three major tank types that may be expected to degrade differently. Therefore, major FTF sources may reasonably be expected to fail at different times spreading doses out over time. In contrast, most of the waste in the SDF is expected to be disposed in FDCs with very similar designs, which may degrade at similar times relative to the multi-thousand year period over which certain key radionuclides are estimated to be released (e.g., I-129, Tc-99).

In some respects, FTF sources appear to be more favorably located than SDF sources because the FTF sources are more perpendicular rather than parallel to groundwater flow (see, e.g., Fig. 4-7 of [17] and Fig. 4.4-12 of [16]). Because SDF sources are more parallel to groundwater flow, SDF sources are expected to have a greater potential for plume overlap. For example, while the eight Type I tanks at the FTF are assumed to fail at the same time in the deterministic analysis, the peak dose from Tc-99 is only approximately a factor of three lower if one tank fails than it is if all eight Type I tanks are assumed to fail at the same time because the plumes do not completely overlap. In the case of SDF, while 64 FDCs are assumed to have the same I-129 and Tc-99 inventories, the peak dose is around a factor of 3 to 4 times higher when all sources are simulated compared to when one FDC nearest the compliance boundary at the location of the peak dose is simulated. Although a larger cumulative effect initially was expected for the SDF, a groundwater divide through the northern section of the SDF and a strong vertical gradient at the SDF both tend to cause plumes to spread out horizontally and vertically in space, thereby mitigating the impact of co-located sources. Therefore, the location of the groundwater divide and the magnitude of the vertical gradient at the SDF, which influence the degree to which plumes overlap, are of importance to the SDF compliance demonstration.

The cumulative impact of multiple sources can also be a function of dispersion. For example, cumulative impacts from Type I tank failures at FTF also are a function of the modeled dispersivity. If less dispersion is assumed, the cumulative impact of Type I failures would be less pronounced. In fact, scoping calculations performed for FTF showed that due to the lower mobility (and dispersion) of Pu-239 in the FTF groundwater model, cumulative impacts from Pu-239 would be less pronounced than they would be for Tc-99.

Inventory distributions are also expected to lead to differences in cumulative impacts from multiple disposal units. For example, because of the relatively high concentrations of key radionuclides in a single tank at FTF (Tank 18), only one tank is expected to be the primary source contributing to the peak doses within 10,000 and 20,000 years for Case A (from Ra-226 and Np-237, respectively) and within 10,000 or 20,000 years for Case G (from Pu-239) (Table II). In contrast, at the SDF the dominant dose contribution comes from Vault 4 under some sets of assumptions and comes from a set of FDCs with overlapping plumes under different assumptions about vault and waste form degradation.

REVIEW CONCLUSIONS

The NRC staff reviews of residual waste disposal in the FTF and salt waste disposal in the SDF focused on physical barriers to flow and chemical barriers to radionuclide release from the waste. Because the waste inventory and concentration at both sites is sufficient to generate unacceptable doses to an off-site member of the public or inadvertent intruder in the absence of engineered barriers, the NRC staff review focused on the engineering features DOE plans to put in place to limit radionuclide release. At the FTF, DOE expects that peak doses are delayed beyond a 10,000 year performance period by a combination of (1) the flow-limiting effect of the steel tank liner and (2) chemical conditions created by the stabilizing grout overlying the waste that limit the solubility of key radionuclides for tens of thousands of years. At the SDF, DOE expects that flow will be significantly limited by water shedding along the closure cap lower drainage layer and that radionuclide release will be further limited by radionuclide precipitation or sorption within the high pH, chemically reducing conditions created within the saltstone waste form. Because the performance of both facilities depends on the performance of engineered barriers for thousands of years, the reviews included a detailed evaluation of the expected long-term behavior of these barriers.

As previously discussed, NRC staff reviews of DOE waste determinations during consultation are designed to evaluate the three NDAA criteria, whereas the review of an updated PA during monitoring only addresses whether the NRC staff has reasonable assurance that the planned disposal action will meet the performance objectives of 10 CFR Part 61. The NRC staff review of the Waste Determination for the FTF did not include conclusions about whether the planned disposal of residual waste at the FTF would meet the NDAA criteria because of the substantial uncertainties in the degree of waste removal DOE would achieve and other technical uncertainties. The main product of the NRC staff review of the planned FTF disposal action is the recommendation that DOE should conduct waste release experiments to increase support for key modeling assumptions related to: (1) the evolution of pH and Eh in the grouted tank system over time; (2) identification of HRR association with solid phases comprising the residual wastes; and (3) expected solubility of HRRs under a range of environmental or service conditions that the residual wastes in the contaminated zone are expected to be exposed to over time. Implementation of this recommendation is deemed crucial for NRC staff to have reasonable assurance that the performance objectives in 10 CFR Part 61, Subpart C can be met. Given the risk-significance of Tank 18 to the overall PA and the short timeline for closure of this tank, the NRC staff recommended that DOE should initiate discussions with NRC staff regarding implementation of this recommendation for Tank 18 as soon as practical. The NRC staff also recommended that experiments to address this recommendation should be conducted prior to final closure of Tank 18. Results of the Tank 18 residual waste experiments, if conducted, will be evaluated by NRC staff to determine the need for additional data collection, experiments, and modeling for Tank 18, as well as other FTF tanks. Additional information regarding the NRC staff's recommendations in this area, including details on the suggested implementation of other recommendations will be provided in the NRC staff's plan for monitoring the FTF later in FY 2012, after DOE makes a final decision on the waste determination.

The NRC staff's review of waste disposal at the SDF is ongoing. When complete, the SDF TER will indicate whether the NRC staff continues to have reasonable assurance that waste disposal at the SDF will meet the performance objectives of 10 CFR Part 61 (NDAA Criterion 3). The TER also will include risk insights that will form the basis of the NRC staff's revised monitoring plan for the SDF. The NRC staff will publish an updated monitoring plan for the SDF later in FY 2012.

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