U.S. Nuclear Regulatory Commission Plan for Monitoring Disposal Actions Taken by the U.S. Department of Energy at the Savannah River Site F-Area Tank Farm Facility in Accordance With the National Defense Authorization Act for Fiscal Year 2005

January 2013

U.S. Nuclear Regulatory Commission
Office of Federal and State Materials
and Environmental Management Programs
Washington, DC 20555-0001

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ACRONYMS AND ABBREVIATIONS

ALARA	As Low As Is Reasonably Achievable
ASR	Alkali Silica Reaction
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CFR	Code of Federal Regulations
CNWRA®	Center for Nuclear Waste Regulatory Analyses
CY	Calendar Year
DOE	United States Department of Energy
EDS	Energy Dispersive Spectroscopy
EPA	United States Environmental Protection Agency
EXAFS	Extended X-Ray Absorption Fine Structure
FEPs	Features, Events, and Processes
FFA	Federal Facility Agreement
FTF	F-Tank Farm or F-Area Tank Farm
FY	Fiscal Year
GCL	Geosynthetic Clay Liner
GCP	General Closure Plan
GSA	General Separations Area
HDPE	High Density Polyethylene
HLW	High-Level Waste
HRR	Highly Radioactive Radionuclide
HTF	H-Tank Farm or H-Area Tank Farm
K_ds	Distribution Coefficients
LLRW	Low-Level Radioactive Waste
LLW	Low-Level Waste
MA	Monitoring Area
MF	Monitoring Factor
NDAA	Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005
NRC	United States Nuclear Regulatory Commission
PA	Performance Assessment
PO	Performance Objective
POC	Point of Compliance
RAI	Request for Additional Information
SCDHEC	South Carolina Department of Health and Environmental Control
SEM	Scanning Electron Microscopy
SRS	Savannah River Site
TER	Technical Evaluation Report
UTRA	Upper Three Rivers Aquifer
WD	Waste Determination
WIR	Waste Incidental to Reprocessing
XANES	X-Ray Absorption Near Edge Structure
XRD	X-Ray Diffraction

DEFINITIONS

As Low As (Is) Reasonably Achievable (ALARA): From 10 Code of Federal Regulations (CFR) 20.1003—Making every reasonable effort to maintain exposures to radiation as far below the dose limits as is practical, consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to the state of technology, the economics of improvements in relation to benefits to public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest.

Disposal: The isolation of radioactive wastes from humans and the environment.

Follow-Up Action: Items identified during monitoring that require additional effort by DOE to resolve. Examples include DOE providing answers to questions generated during technical reviews or DOE providing results of a particular experiment once it becomes available. Follow-up actions are less risk-significant than Open Issues.

High-Level Radioactive Waste (HLW): (i) irradiated reactor fuel; (ii) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing reactor fuel; and (iii) solids into which such liquids have been converted.

Highly Radioactive Radionuclides (also called Key Radionuclides): Those radionuclides that contribute most significantly to risk to the public, workers, and the environment. In the context of the U.S. Nuclear Regulatory Commission (NRC) reviews of DOE Waste Determinations (WDs) conducted under the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005 (NDAA), the term is not limited to radionuclides with high-specific activity. NRC staff considers the term "highly radioactive radionuclides," as used in the context of the NDAA, to be equivalent to the term "Key Radionuclides" used in the manual for DOE Order 435.1 (DOE M 435.1-1), the West Valley Policy Statement, and in some NRC reviews of DOE WDs.

Indeterminate: Insufficient information is currently available to assess compliance with the Performance Objectives (POs) in 10 CFR Part 61, Subpart C. Additional information is forthcoming from DOE within a reasonable timeframe to allow NRC staff to assess compliance with POs.

Monitoring Area (MA): General features or aspects of the disposal action identified by NRC as being important to DOE's ability to meet the POs of 10 CFR Part 61, Subpart C. MAs are further divided into more specific monitoring factors (MF).

Monitoring Factor (MF): Specific features of the disposal action (e.g., conceptual model assumptions, mathematical modeling assumptions, or parameter values) DOE uses in its performance demonstration that NRC has determined to be important to demonstrating compliance with POs of 10 CFR Part 61. NRC typically identifies MFs through the review of a DOE WD, performance assessment (PA), information DOE generates during monitoring (e.g., technical reports on laboratory or field experiments), or other information collected during monitoring (e.g., during NRC observations). MFs are a subset of MAs and tracked as open or closed. When NRC staff determines that an MF is no longer applicable or technical issues or uncertainties are resolved, then the MF is closed.

Onsite: Areas of the DOE site where monitoring activities will be carried out. This may include areas that have some relationship to, but are outside the physical boundaries of a particular Waste Incidental to Reprocessing (WIR) related facility.

Onsite Observation: A formal, preannounced site visit to a DOE WIR related facility by NRC staff for purposes of observing DOE facilities, activities, processes, or experiments related to compliance with 10 CFR Part 61 POs.

Open Issue: An issue that NRC staff identifies during monitoring activities, which requires additional information from DOE to address questions that NRC staff has raised regarding DOE disposal actions. Open Issues can include MFs that DOE has not taken sufficient action to address or instances where data collected by DOE are not consistent with assumptions (e.g., conceptual model assumptions, mathematical assumptions, or parameter values) made in the PA. Open Issues are more risk significant than follow-up actions, and the term Open Issues indicates items that could lead to noncompliance with the POs.

Operations: The time frame during which DOE carries out its waste disposal actions, through the end of the institutional control period. For the purpose of this monitoring plan, DOE actions involving waste disposal are considered to include PA development (analytical modeling), waste removal, grouting, stabilization, observation, maintenance, or other similar activities.

Performance Assessment: A type of systematic (risk) analysis that addresses (i) what can happen, (ii) how likely it is to happen, (iii) what the resulting impacts are, and (iv) how these impacts compare to specifically defined standards.

Performance Objectives: One of the 10 CFR Part 61, Subpart C, requirements for low-level waste (LLW) disposal facilities, which are (i) general requirement (10 CFR 61.40), (ii) protection of the general population from releases of radioactivity (10 CFR 61.41), (iii) protection of individuals from inadvertent intrusion (10 CFR 61.42), (iv) protection of individuals during operations (10 CFR 61.43), and (v) stability of the disposal site after closure (10 CFR 61.44).

Recommendations: NRC suggestions DOE might consider to further enhance its approach for management of incidental waste. Recommendations are typically made during the consultation phase. Unlike follow-up actions and Open Issues, recommendations are not tracked during monitoring.

Technical Review: NRC technical staff review of reports, studies, analyses, experiments, and other information prepared by DOE, South Carolina Department of Health and Environmental Control, or other stakeholders that may confirm or refute DOE’s ability to meet 10 CFR Part 61 POs with respect to its WIR disposal activities.

Waste Determination (or Non-High-Level Waste Determination): DOE documentation required by Section 3116 of the NDAA that demonstrates that a specific waste stream is not HLW.

Worker: DOE personnel or contractors who carry out operational activities at the disposal facility.

EXECUTIVE SUMMARY

The Ronald Reagan National Defense Authorization Act for Fiscal Year 2005 (NDAA) authorizes the U.S. Department of Energy (DOE) in consultation with the U.S. Nuclear Regulatory Commission (NRC) to determine whether certain radioactive waste related to reprocessing of spent nuclear fuel is not high-level waste (HLW), provided certain criteria are met. The NDAA applies specifically to DOE facilities in South Carolina and Idaho and not to similar DOE facilities located in other states. The NDAA also requires NRC to coordinate with the covered state (i.e., South Carolina or Idaho) to monitor DOE disposal actions to assess compliance with the Performance Objectives (POs) for low-level waste (LLW) in 10 *Code of Federal Regulations* (CFR) Part 61, Subpart C. These POs include (i) general requirement (10 CFR 61.40), (ii) protection of the general population from releases of radioactivity (10 CFR 61.41), (iii) protection of individuals from inadvertent intrusion (10 CFR 61.42), (iv) protection of individuals during operations (10 CFR 61.43), and (v) stability of the disposal site after closure (10 CFR 61.44). This monitoring plan details the NRC's path forward to assessing DOE's compliance with each of these POs for residual waste remaining in the HLW tanks at the Savannah River Site (SRS) near Aiken, South Carolina, at the time of facility closure.

In fiscal year 2010, DOE issued a draft Waste Determination (WD) that concluded that stabilized waste residuals in F-Area Tank Farm facility (FTF) tanks and auxiliary components, as well as the tanks and auxiliary components themselves, could meet NDAA criteria for Waste Incidental to Reprocessing at the time of closure and as such could be managed as LLW. As required by the NDAA, DOE consulted with NRC regarding the conclusions in its draft WD for FTF. Results of a multi-year consultative review culminated in NRC staff's issuance of a Technical Evaluation Report (TER) in October 2011 (NRC, 2011). As DOE is in the early years of closure for FTF, limited information regarding important factors influencing facility performance has been generated. Therefore, rather than reaching conclusions regarding DOE's ability to meet the POs in 10 CFR Part 61, Subpart C, NRC staff instead provided a series of comments and recommendations in its TER (NRC, 2011). If addressed by DOE, NRC staff expects these comments and recommendations will improve DOE's compliance demonstration. NRC staff reasons that sufficient time is available for DOE to implement many of these recommendations as FTF closure progresses.

In limited cases, NRC staff recommended actions that it deemed critical to DOE's compliance demonstration in the short-term. These more critical recommendations generally involved issues associated with one tank at FTF, Tank 18, which was scheduled for closure in calendar year (CY) 2012. Tank 18 is predicted by DOE models to produce overall peak doses significantly above the POs in 10 CFR 61.41 and 61.42 considering longer performance periods beyond 10,000 years. Given the magnitude of the dose predictions and uncertainty in the timing of the peak dose, NRC staff recommended that technical issues associated with Tank 18 (e.g., support for release and natural attenuation assumptions) should be resolved prior to tank grouting to inform closure of this single tank as well as future FTF tank closures.

Notwithstanding NRC staff's recommendation to delay grouting of Tank 18, DOE issued a final WD in March 2012 (DOE/SRS–WD–2012–001) and commenced grouting of Tanks 18 and 19 in April 2012[1]. DOE indicated in its final WD that it considered the assumptions, conclusions, and recommendations documented in NRC's TER (NRC, 2011). In fact, a number of studies were

[1]NRC staff concluded in its TER (NRC, 2011), that due to the relatively low residual inventory and risk associated with Tank 19, DOE could proceed with closure of Tank 19.

conducted by DOE between NRC's issuance of its TER and DOE's issuance of its final WD to address NRC staff's technical concerns. Because DOE conducted significant work on reducing the technical uncertainties associated with Tank 18 prior to issuance of the final WD for FTF, NRC staff is in the process of reviewing the additional information DOE generated in support of the final WD to reach a conclusion regarding the ability of the FTF to meet the POs in 10 CFR Part 61, Subpart C. Where appropriate, NRC staff lists specific monitoring activities related to Tank 18, including technical reviews of documents and activities generated or performed by DOE during the interim period between NRC's issuance of its TER and DOE's final WD for FTF, as well as future planned activities that have not yet occurred for Tank 18 and the larger FTF.

In accordance with the NDAA, NRC will assess FTF compliance with the POs in 10 CFR Part 61, Subpart C. A performance assessment (PA) is typically used to demonstrate compliance with two of the four POs, 10 CFR 61.41, "Protection of the General Population From Releases of Radioactivity," and 61.42, "Protection of Individuals From Inadvertant Intrusion," which are assessed using dose-based criteria. A PA is a type of systematic risk analysis that addresses (i) what can happen, (ii) how likely it is to happen, (iii) what the resulting impacts are, and (iv) how the impacts compare to specifically defined standards. Considering the long time period over which long-lived radionuclides pose a hazard to human health, a robust PA is needed to establish that the POs will be met for releases from the FTF that may occur many thousands of years in the future. NRC considers sufficient PA model support, coupled with an observation of disposal actions that are carried out in conformance with detailed closure plans, necessary for NRC to have reasonable assurance that the POs can be met. Many key features of DOE's disposal facility design are important to the FTF compliance demonstration, as documented in the FTF PA. These key features are the focus of NRC staff's monitoring efforts.

NRC's monitoring plan focuses on the most risk-significant aspects of DOE disposal actions. These risk-significant aspects were identified in eight monitoring areas (MA). The first six MAs relate to general public and intruder protection. NRC staff developed MA 1, "Residual Waste Inventory" to ensure that the final post cleaning inventory that is developed for each cleaned tank is consistent with assumptions made in DOE's final WD and PA regarding the final waste inventory at closure. NRC also will perform monitoring activities related to engineered and natural features of the disposal facility that also are found to be important to meeting the POs. NRC staff developed MA 2 "Waste Release" to ensure that releases of key radionuclides remain low for long periods of time. NRC staff developed MA 3 "Cementitious Material Performance" to ensure that cementitious materials act as effective barriers to fluid flow, mitigate or attenuate releases of radioactivity from the tanks, and otherwise perform consistent with DOE PA assumptions. NRC staff developed MA 4 "Natural System Performance" to ensure the hydrogeological system acts as an effective natural barrier to attenuate key radionuclide releases. Additionally, under MA 4, NRC staff will review environmental data collected by DOE as an additional assurance that the FTF is operating as predicted by DOE models. NRC staff developed MA 5 "Closure Cap Performance" to evaluate key features of the closure cap identified in NRC staff's review. All of these MAs are directly related to the facilities' long-term ability to limit or mitigate releases of contaminants from the FTF that could result in adverse human health impacts. Items of lower risk significance or longer-term activities are addressed in MA 6 "PA Maintenance." PA maintenance also is necessary to ensure that a mechanism is in place to consider new and significant information that may be collected in the future that might significantly alter results presented in DOE's PA.

While DOE relies on a PA to demonstrate compliance with POs related to general public and intruder protection, NRC can evaluate compliance with 10 CFR 61.43, "Protection of Individuals During Operations," through direct observation of DOE closure activities. NRC plans to perform a graded review of DOE's radiological protection program while observing DOE's most risk significant closure activities (e.g., tank cleaning and grout placement activities) to assess compliance with 10 CFR 61.43. For example, NRC staff will review radiation records and environmental data or reports and possibly conduct interviews during closure activities to assess compliance with 10 CFR 61.43 addressed under MA 7 "Protection of Individuals During Operations."

Finally, monitoring activities to assess compliance with 10 CFR 61.44, "Stability of the Disposal Site After Closure," partially overlap those activities developed to support assessment of compliance with 10 CFR 61.41 and 61.42. NRC considers unique factors affecting stability of the disposal site not already discussed under 10 CFR 61.41 and 61.42 under MA 8 "Site Stability."

To prepare this monitoring plan, NRC staff began by comprehensively considering all of its previous comments and recommendations on each FTF PA and WD review and cross-walked each of the items to one of the eight MAs described above that NRC considers important to DOE's compliance demonstration[2]. This cross-walk is provided in Appendix A. As such, this monitoring plan will serve as the starting point from which NRC staff will assess compliance with the POs in 10 CFR Part 61, Subpart C in fulfillment of its monitoring responsibilities under the NDAA. As discussed in the preceding paragraphs, the eight MAs are:

- MA 1 "Residual Waste Inventory"
- MA 2 "Waste Release"
- MA 3 "Cementitious Material Performance"
- MA 4 "Natural System Performance"
- MA 5 "Closure Cap Performance"
- MA 6 "PA Maintenance"
- MA 7 "Protection of Individuals During Operation"
- MA 8 "Site Stability"

MAs are supported by a number of monitoring factors (MFs). MFs are smaller, more specific items that NRC staff will investigate in more detail. MFs will help facilitate monitoring by providing specific activities for NRC staff to focus on. These MFs will be tracked as open or closed. If issues arise related to MFs, NRC staff may develop an "open issue" to document concerns related to the MF. In this way, NRC staff will have a mechanism to communicate to DOE early in the process the need for corrective action, prior to issuance of a notification letter of concern or noncompliance. NRC staff will note the status of each MF in the periodic monitoring compliance reports, currently prepared annually, for the Idaho National Laboratory and SRS, NUREG–1911.

Because Congress directed NRC to monitor DOE disposal actions to assess compliance with the POs in 10 CFR Part 61, Subpart C, this monitoring plan is first organized by PO, with four chapters each devoted entirely to one of the four POs. As indicated above, NRC staff evaluates what key MAs are important to DOE's demonstration of compliance with each PO—MAs are,

[2]NRC recognizes that some of its previous review comments and recommendations are less risk-significant or may require longer time periods to address than others. Lower risk or long-term activities are binned into MA 6 titled "PA Maintenance."

therefore, listed directly beneath each PO and support NRC staff's assessment of FTF facility compliance with the POs, as required by the NDAA. As stated above, each MA supports one or more POs. If the MA supports multiple POs, the monitoring plan will indicate whether the MA and underlying factors are an exact duplicate of a previously listed MA (in which case the MA and factors will not be repeated) or if there are unique aspects of the MA or underlying factors that pertain to just that PO (in which case only the unique aspects of the area and relevant factors will be discussed under the PO). Table ES–1 lists each MA and indicates the POs each MA supports.

Table ES–2 provides NRC staff's prioritization of each MF under MAs 1–5 developed to support the 10 CFR 61.41 PO. Many of these factors also support the 10 CFR 61.42 PO because an inadvertent intruder also is assumed to be exposed to FTF waste through the groundwater pathway. MA 6, "Performance Assessment Maintenance," MFs are not listed in Table ES–2 because PA Maintenance items are considered items of lower risk significance or longer-term monitoring activities by default. Each of these MFs is developed in more detail in the chapters that follow.

This monitoring plan also provides information regarding the types of monitoring reports NRC plans to prepare to document its monitoring activities. For example, NRC plans to issue a report following each onsite observation and will summarize monitoring activities and changes to the status of its monitoring activities in periodic reports. If NRC is unable to conclude POs are met, NRC will notify DOE, the covered State, and Congress, as required by the NDAA. The types of notification letters related to a finding of non-compliance are listed in Section 1.9 of this document.

Table ES–1. List of Monitoring Areas and Associated Performance Objectives

MA	**Monitoring Areas**	**10 CFR Subpart C Performance Objective**			
		61.41	**61.42**	**61.43**	**61.44**
1	Inventory	X	X		
2	Waste Release	X	X		
3	Cementitious Material Performance	X	X		
4	Natural System Performance	X	X		
5	Closure Cap Performance	X	X		
6	Performance Assessment Maintenance	X	X		
7	Protection of Individuals During Operations			X	
8	Site Stability				X

Table ES–2. NRC Prioritization of Monitoring Factors That Support 10 CFR 61.41 and 61.42

MA 1 Inventory	MA 2 Waste Release	MA 3 Cementitious Material Performance	MA 4 Natural System Performance	MA 5 Closure Cap
1.1— Final Inventory and Risk Estimates†	2.1— Solubility-Limiting Phases/Limits and Validation§	3.1— Cement Vault Performance (As It Impacts Steel Liner Corrosion)‡	4.1— Natural Attenuation of Pu§	5.1— Long-Term Hydraulic Performance*
1.2— Residual Waste Sampling†	2.2— Chemical Transition Times‡	3.2— Groundwater Conditioning‡	4.2— Calcareous Zone Characterization†	5.2— Long-Term Erosion Protection Design*
1.3— Residual Waste Volume†		3.3— Shrinkage and Cracking†	4-3— Environmental Monitoring†	
1.4— Ancillary Equipment Inventory*		3.4— Grout Performance†		
1.5— Waste Removal (As It Impacts As Low As Is Reasonably Achievable)*		3.5— Basemat Performance‡		
		3.6— Grout Stabilization (As It Impacts As Low As Is Reasonably Achievable)*		

*Lower Priority

†Medium Priority

‡High Priority Dependent or More Difficult *(The monitoring factors in orange‡ are risk-significant to the U.S. Department of Energy's performance assessment, but the need for their implementation may be dependent on results of other monitoring factors. Because the monitoring factors in orange‡ are also expected to be more difficult to study or support, work on monitoring factors in red§ are recommended first.)*

§High Priority Recommended

References

DOE/SRS–WD–2012–001, Rev. 0, “Basis for Section 3116 Determination for Closure of F-Tank Farm at Savannah River Site.” Washington, DC: U.S. Department of Energy. 2012.

NRC. “Technical Evaluation Report for F-Area Tank Farm Facility, Savannah River Site, South Carolina—Final Report.” ML112371715. Washington, DC: U.S. Nuclear Regulatory Commission. 2011.

DOE/SRS–WD–2012–001, Rev. 0, “Basis for Section 3116 Determination for Closure of F-Tank Farm at Savannah River Site.” Washington, DC: U.S. Department of Energy. 2012.

1 MONITORING PROCESS

1.1 Background

The Savannah River Site (SRS) is an 803 square kilometer (310 square mile) facility developed in the 1950s as part of the country's growing weapons program. Many activities took place at the site, including the reprocessing of spent nuclear fuel in reinforced concrete buildings called canyons. Liquid waste from the reprocessing process was managed in 51 underground storage tanks. The F-Area Tank Farm (FTF), the subject of this monitoring plan, contains 22 of these tanks.

The U.S. Department of Energy (DOE) is engaged in an expansive campaign to clean, stabilize and close 20 of the 22 underground waste storage tanks at the FTF. DOE closed two FTF tanks (Tanks 17 and 20) in the 1990's prior to U.S. Nuclear Regualtory Commission (NRC) involvement in the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005 (NDAA). DOE clean up activities also include support ancillary structures (i.e., evaporators, pump pits, pump tanks, diversion boxes, transfer valve boxes, and piping) used to store, treat, and transfer generated waste. The waste tanks and ancillary structures are several decades old. The original service life for these tanks was projected as 40 years; however, several of the aging FTF waste tanks are approaching 60 years of service life. Given the inherent risks of exhuming the aging waste tanks and disposing them as high-level waste (HLW), DOE plans to clean, grout and close the FTF waste tanks and ancillary structures that are in place to reduce the risks to the workers, the public, and the environment.

In accordance with Section 3116 of the NDAA, the Secretary of Energy, in consultation with NRC on March 27, 2012, made a determination that waste remaining within the tanks and ancillary facilities in FTF does not have to be considered or managed as HLW, to be disposed in a geologic repository. Rather, it can be disposed of, in place, as low-level waste (LLW).

NRC's consultation included the review of a draft waste determination (WD) basis document, which DOE submitted in September 2010. A detailed site performance assessment (PA) accompanied the basis document (SRS–REG–2007–00002, Rev. 1). During the review process, NRC staff held a number of technical exchange meetings with DOE and submitted a written Request for Additional Information regarding certain aspects of the DOE basis document (NRC, 2010). DOE completed its response to NRC in the summer of 2011. NRC staff completed a technical evaluation report (TER) in October 2011 (NRC, 2011). In its TER, NRC staff provided a number of recommendations to DOE that, if implemented, would increase the likelihood that NRC would find the FTF in compliance with the 10 *Code of Federal Regulations* (CFR) Part 61, Subpart C performance objectives (POs). DOE submitted additional information regarding several NRC TER recommendations prior to completing the final WD (DOE/SRS–WD–2012–001) and has plans to address other NRC recommendations, as indicated in its "Savannah River Site Liquid Waste Facilities Performance Assessment Maintenance Program, fiscal year 2012 Implementation Plan" (SRR–CWDA–2012–00020).

NRC assumed its monitoring role, per the NDAA, once DOE issued its WD in March 2012 for the remaining tanks and ancillary structures at the FTF facility. The NDAA provides a very specific responsibility for NRC to monitor disposal operations to ensure DOE disposal actions comply with the POs in 10 CFR Part 61. While NRC staff reviewed and provided comments on DOE's PA and the entire FTF WD, NRC's TER (NRC, 2011) included a more detailed evaluation of the effectiveness of completed waste removal activities for Tanks 18 and 19 and provided recommendations related specifically to the closure of those two tanks that were further along in the closure process and for which DOE provided more detailed closure information. This is important to note since the monitoring plan will include 20 tanks in FTF, including 16 tanks for which little or no waste removal has occurred. Over the next several decades, DOE will complete many activities to affect tank cleaning and closure in accordance with its responsibilities under the Federal Facility Agreement (FFA) to which NRC is not a party. NRC's monitoring activities will focus on heel removal after much of the bulk removal of waste from the tanks has been completed.

1.2 Objective

In accordance with Section 3116 of NDAA, after the Secretary of Energy has made a determination that some residual waste does not have to be managed as HLW, NRC is required to monitor subsequent disposal activities to assess compliance with the POs in 10 CFR Part 61, Subpart C. NRC must coordinate these monitoring activities with the South Carolina Department of Health and Environmental Control (SCDHEC), the primary site regulator.

This monitoring plan describes monitoring activities to be conducted in the context of their relationship with the ability for DOE to comply with the 10 CFR Part 61, Subpart C POs. In most cases, compliance or potential noncompliance with the POs must be demonstrated through indicators of future performance. The monitoring plan identifies eight Monitoring Areas (MAs) that NRC and SCDHEC finds to be important to demonstrating compliance with the POs. DOE activities associated with disposal of tanks and associated waste will take decades to complete. NRC anticipates that implementation of this monitoring plan will take place concurrently with DOE closure activities. NRC staff activities related to the MAs will include the following:

- Technical reviews of DOE work products, experiments, and analyses tied to one or more MAs, including collection of environmental data.

- Periodic onsite (quarterly or less frequent) observations of aspects of DOE disposal activities and, as appropriate, related experiments.

NRC monitoring activities will be accomplished by NRC headquarters and regional personnel. In general, NRC staff will work in concert with SCDHEC personnel regarding accomplishment of monitoring tasks supportive of each organization's program.

1.3 Roles and Responsibilities

U.S. Department of Energy

The SRS FFA (WSRC–OS–94–42), a formal agreement between DOE, Region IV of the U.S. Environmental Protection Agency (EPA), and SCDHEC specifies the order and time in which FTF waste tanks are closed. The organizations who are parties in the FFA have regulatory authority over certain activities at SRS. NRC is not a party to the FFA and does not have regulatory authority over waste disposal activities.

The FFA establishes that, among other things, the SRS waste tanks that do not meet secondary containment standards (older style tanks, specifically Types I and IV in FTF) must be removed from service according to the FFA schedule. The current FFA calls for operational closure of Tanks 18 and 19 by December 2012 and staggered operational closure of the other eight

FTF (Type I) waste tanks (tank numbers not specified in the FFA) by September 2022 (WSRC–OS–94–42). DOE addresses the closure of the remaining FTF tanks (Types III and IIIA) and ancillary structures in the SRS Liquid Waste System Plan (SRR–LWP–2009–00001).

DOE will, pursuant to its authority, pursue closure of the FTF and monitor its activities to ensure compliance with all requirements. DOEs relevant authority stems from the Atomic Energy Act of 1954, as amended, and applicable DOE Orders, manuals and policies. Furthermore, DOE uses a documented process to review and resolve any disposal questions and develop any mitigation measures, as appropriate. Tank waste storage and removal operations are governed by an SCDHEC industrial wastewater construction permit (DHEC–01–25–1993). DOE will carry out removal from service and stabilization of the FTF waste tanks and ancillary structures pursuant to a State-approved closure plan, the FTF General Closure Plan, which contains the overall plan for removing from service and stabilizing the FTF waste tanks and ancillary structures (LWO–RIP–2009–00009). A specific Closure Module for each waste tank or ancillary structure or groupings of waste tanks and ancillary structures will be developed and submitted to the State of South Carolina for approval. Final waste tank stabilization activities shall not proceed until the State of South Carolina grants approval. Stabilization of individual FTF waste tanks and ancillary structures is anticipated to take place after individual component cleaning is complete.

South Carolina Department of Health and Environmental Control

SCDHEC is the primary regulator of DOE closure activities at SRS. The FTF waste storage and removal operations are governed by an SCDHEC industrial wastewater construction permit, issued January 25, 1993 (DHEC–01–25–1993). The State issued the permit under the authority of the South Carolina Pollution Control Act (State of South Carolina, 1985, Section 48-1-10) and all applicable regulations implementing the Act. The State of South Carolina has authority for approval of wastewater treatment facility operational closure under Chapter 61, Articles 67 and 82 of the SCDHEC Regulations (SCDHEC R.61-67, SCDHEC R.61-82).

The FTF GCP addresses the State's regulatory authority relevant to removing the FTF waste tanks and ancillary structures from service. The GCP sets forth the general protocol by which DOE intends to remove from service the FTF waste tanks and ancillary structures to protect human health and the environment. The SCDHEC approved the FTF GCP on January 24, 2011. Prior to approval by SCDHEC, the FTF GCP was made available to the public for review and comment (LWO–RIP–2009–00009).

U.S. Environmental Protection Agency

As previously stated, the FFA is an agreement between the EPA, DOE, and the State of South Carolina. EPA is a party to the FFA pursuant to its authority in accordance with the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), also known as Superfund, under which EPA is tasked with protecting citizens from the dangers posed by abandoned or uncontrolled hazardous wastes. EPA's involvement with the State is focused on ensuring that proper disposal actions are taken, assisting the state with the design and installation of those actions, and monitoring and evaluating their effectiveness.

Executive Order 12580 delegates the responsibility to implement the provisions in CERCLA to DOE and the U.S. Department of Defense. CERCLA also names DOE and DOD as the lead agencies for their respective areas. DOE has several facilities in EPA's Region IV. EPA added

SRS to the Superfund National Priorities List in December 1989, which also is the year that SRS was required to have an FFA with the State and EPA.

U.S. Nuclear Regulatory Commission

Section 3116 of the NDAA authorized the Secretary of Energy to manage and dispose of certain waste associated with facility clean-up in Idaho and South Carolina as LLW, in accordance with POs in NRC regulations. Prior to such a determination, DOE is required to consult with NRC regarding its WD. Following the Secretary's WD, NRC is required to monitor disposal activities in coordination with the covered State.

NRC's role in monitoring DOE's closure activities derives from Section 3116 of the NDAA. While NRC is not given a formal regulatory role, the NDAA requires that NRC monitor, in coordination with SCDHEC, DOE disposal activities to assess compliance with the POs in 10 CFR Part 61. Thus, DOE complies with a subset of NRC regulations in 10 CFR Part 61 "Licensing Requirements Land Disposal of Radioactive Waste" in carrying out such disposal activities. The regulations in Part 61 establish, for land disposal of radioactive waste, procedures, criteria, and terms and conditions upon which NRC issues licenses for the disposal of radioactive wastes containing byproduct, source, and special nuclear material received from other persons.

NRC recognizes that many of the activities that DOE must carry out prior to tank closure are beyond the scope of NRC monitoring authority. For instance, NRC is concerned with and will monitor aspects of residual waste inventory in each tank because of its direct relationship to compliance with the POs. However, NRC staff will focus only on more risk-significant activities related to the residual waste inventory. For example, while NRC staff will monitor heel removal activities insofar as these activities pertain to as low as is reasonably achievable provisions in 10 CFR 61.41, NRC staff does not plan to monitor more routine inventory-reducing activities, such as bulk waste removal.

This monitoring plan articulates NRC's role to ensure DOE disposal activities associated with residual waste covered by the Secretary of Energy's WD are in compliance with the POs of 10 CFR Part 61.

1.4 Coordination With the State of South Carolina

Per Section 3116 of NDAA, NRCs monitoring role includes coordination with State of South Carolina. During the WD review, NRC staff began coordinating with SCDHEC by conducting discussions to determine the types of activities that the State monitors under its regulatory authority. These discussions also enabled the State to get a better understanding of NRC's activities. NRC continues to coordinate with the SCDHEC throughout the monitoring process by consulting with SCDHEC in the development of this monitoring plan and reviewing the State's Environmental Surveillance and Oversite Program for use as a source of information to supplement NRC's monitoring plan. SCDHEC uses a holistic monitoring approach with regard to overall performance and safety of SRS. The NRC objective with this NDAA monitoring program is limited to assessment of DOE's compliance with the 10 CFR Part 61 POs. Ultimately, NRC and SCDHEC are concerned with the potential for environmental contamination in ground and surface water, air, milk, and meat. While it is unlikely that any contribution to such contamination from FTF could manifest itself offsite in the foreseeable future, it is important to consider, and evaluate to the extent practicable, the utility of environmental monitoring in assessing compliance with the POs.

During the monitoring phase, NRC activities will be closely coordinated with SCDHEC. To the extent practical, NRC will request SCDHEC's assistance in following up on certain monitoring activities that require a local or onsite presence (e.g. activities related to daily tank grouting activities). SCDHEC also will be invited to contribute to the development of monitoring reports as well as the overall monitoring plan.

NRC will keep the State abreast of the status of monitoring activities at the site, including any potential findings of noncompliance that require a notification letter as described in Section 1.7 of this Monitoring Plan. At least two business days prior to the release and dissemination of any notification letters, SCDHEC officials will be briefed, in detail, on the reasons for such notification.

1.5 Monitoring Approach

Monitoring is an ongoing process consisting of technical reviews, data reviews, and periodic (i.e., quarterly or less frequently) onsite observation visits of DOE disposal activities related to compliance with the 10 CFR Part 61 POs.

1.5.1 Technical Reviews

Technical reviews by NRC include review and evaluation of analyses conducted by DOE or others that confirm one or more aspects of site performance. Also, reviews are used to obtain additional model support for assumptions made by DOE in the PA that are considered important to DOE compliance demonstration. NRC will document each review, which will be publicly available (e.g., Note to File and report for an Onsite Observation Visit).

1.5.2 Data Reviews

Data reviews focus on real-time monitoring data that may indicate future system performance or a review of records or reports that can be used to directly assess compliance with POs (e.g., review of radiation records). NRC will document each review, which will be publicly available (e.g., Note to File and report for an Onsite Observation Visit).

1.5.3 Onsite Observation Visits

As described in NUREG–1854 (NRC, 2007), onsite observation visits are opportunities for NRC to observe and review certain operations as they are being performed. Onsite obseravtions visits are performed by NRC staff or a representative and may include a variety of specific activities that could be used to assess an aspect of current or future site performance. A visit is generally performed to either (i) ensure data collected for a technical review are of sufficient quality or (ii) observe key disposal actions that are important to DOE's compliance demonstration.

Prior to each onsite observation visit, NRC will prepare an Observation Guidance Memorandum that discusses the scope and specific activities that will be monitored during the visit in more detail than is described in this monitoring plan. The activities NRC selects will be based on many aspects, such as completion of DOE technical reports, emergent issues, timely DOE actions related to a monitoring factor (MF), availability of staff (i.e., NRC, SCDHEC, DOE), availability of locations at the site, length of time since reviewing an item in an MF, scheduled follow-up actions to previous visits, and available NRC resources. NRC will coordinate with SCDHEC in development of the memorandum to take into account areas that SCDHEC is interested in and availability of SCDHEC experts in those areas of interest. NRC plans to provide the final memorandum to DOE within 30 calendar days prior to the visit. The final memorandum will be publicly available. During a visit, the agenda may change based on what happens during the visit (e.g., new areas of interest are identified) or unforeseen circumstances.

Each visit will be documented in an observation report. The report will include, for the actual areas covered during the visit, specific activities, results of discussions, status of any open issues/follow-up actions, and any NRC conclusions. The areas covered may differ somewhat from the areas of interest identified in the Observation Guidance Memorandum. NRC plans to finalize each report within 60 calendar days after the visit. The final report will be publicly available.

1.6 Annual Compliance Monitoring Report

NRC will publish an Annual Compliance Monitoring Report [i.e., currently, NUREG–1911 (NRC, 2012)] to document the major findings associated with the monitoring activities during each calendar year (CY). The report will be for the entire NRC NDAA program for that CY and will be publicly available.

1.7 Notification Letters

In accordance with NRC guidance in NUREG–1854 (NRC, 2007), there are five types of notification letters. Three of the letters are non-compliance letters (i.e., Types I to III) that NRC developed to implement the authority it has inferred from the statutory language in Section 3116 of the NDAA and two other types of letters that NRC may issue as an interim step when identifying or resolving major issues. NRC may issue a Type IV letter to express a concern and a Type V letter to confirm resolution of a concern. Table 1-1 describes each of the five letters, including NRC’s reason for issuing the letter, who at NRC signs the letter, and who receives the letter. The information in Table 1-1 is similar to the information in NUREG–1854 (NRC, 2007, Table 10-2), but is supplemented by information that reflects current experiences and lessons learned from previous monitoring activities.

Figure 1-1 shows the types of noncompliance with the POs in 10 CFR Part 61, Subpart C, which are based on the collection of indirect and direct evidence.

1.8 Monitoring Plan

This monitoring plan presents the basic framework for NRC to perform monitoring activities in accordance with the NDAA for the FTF. The monitoring plan starts with the high level consideration of the four POs. Under each PO, the relevant MAs are identified. Each MA contains a set of MFs important to DOE’s compliance demonstration. New MAs are not expected in the future; but, they may be identified and added to the monitoring plan. The MFs were created from the concerns identified in NRC’s TER (NRC, 2011). These concerns will now be addressed under the MFs in this monitoring plan.

Table 1-1. Types of Notification Letters			
Type	**Description/Notification**	**Signature**	**Distribution**
Non-Compliant Performance Objective Notifications			
I	<u>Evidence Performance Objective Is Not Met</u> NRC staff concludes that direct evidence (e.g., environmental sampling data) exists that indicates DOE disposal actions do not meet one or more performance objectives in 10 CFR Part 61, Subpart C. Notification: NRC will issue a Type I letter of noncompliance if DOE cannot demonstrate that disposal actions currently meet the requirements specified in the performance objectives.	Chairman	DOE, Covered State, and Congress
II	<u>Lack of Compliance Demonstration</u> NRC staff concludes that indirect evidence (e.g., experimental data on a key modeling assumption) exists that indicates DOE disposal actions do not meet one or more of the performance objectives in 10 CFR Part 61, Subpart C. Notification: NRC will issue a Type II letter of noncompliance if DOE cannot adequately address NRC technical concerns.	Chairman	DOE, Covered State, and Congress
III	<u>Insufficient Information</u> NRC staff concludes that insufficient information is available to assess whether DOE disposal actions meet the performance objectives in 10 CFR Part 61, Subpart C. It is not clear to NRC staff that DOE (i) has plans to or (ii) is able to provide the information in a reasonable timeframe to allow NRC staff to assess compliance. Notification: NRC will issue a Type III letter of noncompliance if DOE cannot adequately address NRC technical concerns.	Chairman	DOE, Covered State, and Congress
Other Notification Letters			
IV	<u>Concern</u> NRC staff has concerns with the performance demonstration.	NRC Staff Management	DOE and Covered State
V	<u>Resolution</u> DOE has provided sufficient information to resolve NRC staff's concerns with the performance demonstration.	NRC Staff Management	DOE and Covered State
Note: If practical, NRC staff will attempt to issue a notification letter of concern (Type IV letter) to allow DOE sufficient time to respond to NRC staff concerns prior to issuance of one of the three notification letters of noncompliance (Types I to III) listed above.			

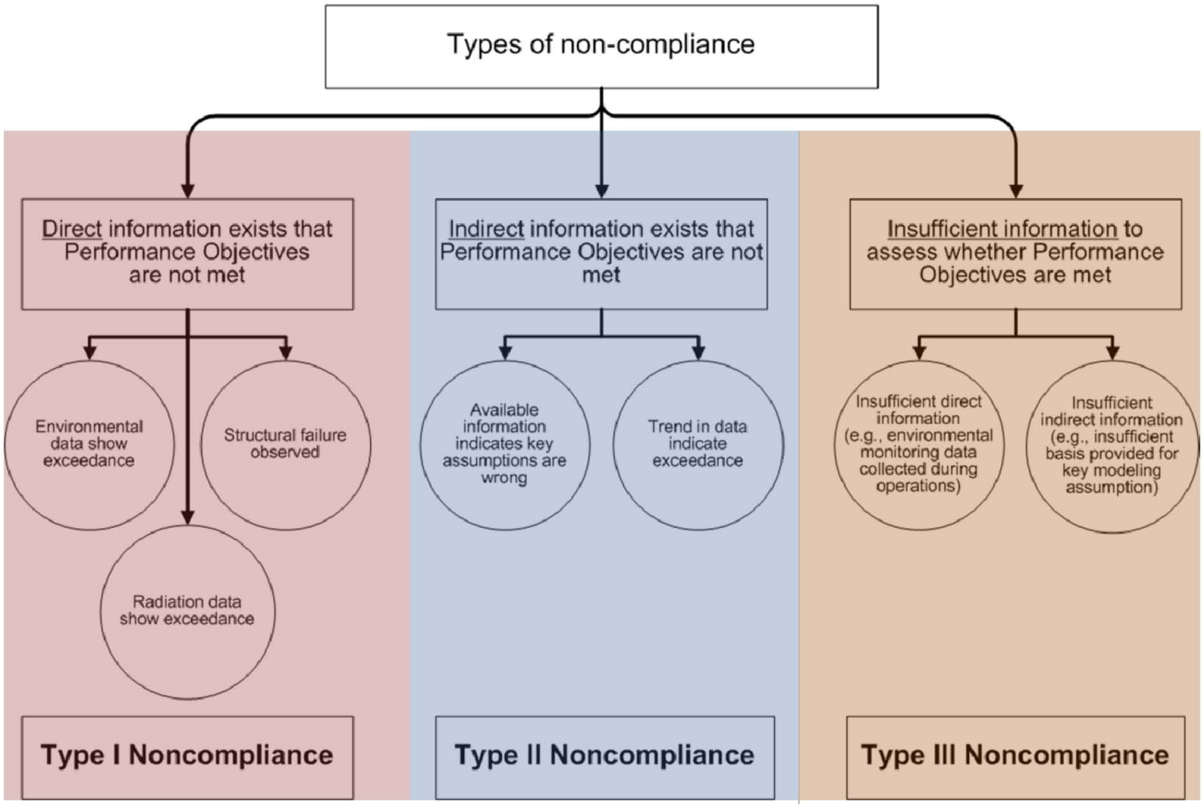

Figure 1-1. Types of Non-Compliance With the Performance Objectives in 10 CFR Part 61, Subpart C

The identification, description, and status (i.e., open or closed) of each MF will evolve as monitoring activities continue in the future. New MFs are expected to be added to the monitoring plan in the future, as more information is known about the future DOE disposal actions and experiments. After each onsite observation visit, NRC will issue a report that will document status of each open MF or open issue. NRC expects to issue more revisions to the monitoring plan in the future to address such items as an updated DOE PA or a new NRC TER.

1.8.1 Linkage Between Recommendations in the Technical Evaluation Report and Monitoring Factors

Appendix A provides a crosswalk between each consultative review comment or recommendation to the MAs and factors developed in this monitoring plan. Appendix A also provides a crosswalk between NRC staff's PA maintenance items binned under MA 6 and DOE's Performance Assessment Maintenance Plan (SRR–CWDA–2012–00020).

1.8.2 Closing Monitoring Factors

NRC will document closure of MFs (e.g., TER, technical review memorandum, or annual monitoring compliance report). To the extent practical, the information needed by NRC staff to close an MF is provided in Chapters 3 through 6, following each MF identified herein. NRC anticipates that as DOE tank farm closure activities continue, it will identify additional MFs. In general, DOE must provide transparent and technically robust reports, studies, analyses, or experiments that specifically address the technical issues associated with each MF.

2 MONITORING TO ASSESS COMPLIANCE WITH 10 CFR 61.40

Land disposal facilities must be sited, designed, operated, closed, and controlled after closure so that reasonable assurance exists that exposures to humans are within the limits established in the performance objectives (PO) in 10 Code of Federal Regulations (CFR) 61.41 through 61.44.

The requirements in 10 CFR Part 40 are general requirements for near-surface disposal of low-level waste. The Department of Energy (DOE) disposal actions at F-Area Tank Farm (FTF) are unique in that the site and the waste are preexisting. Consequently, certain activities specified in the POs are limited in applicability. Siting requirements do not apply and design is only applicable with respect to the prospective design features of waste disposal, as described in the waste determination (WD). These might include such things as design of the grout mix introduced to the tanks and the site cover. Other activities (i.e., operations, use, closure, and postclosure) are applicable as they relate to disposal of waste covered by the WD.

This section requires reasonable assurances that exposures to humans are within the limits established in the other four POs (i.e., 10 CFR 61.41 through 61.44). If DOE provides reasonable assurance that it will meet the other four POs, then DOE will likely have met 10 CFR 61.40. If DOE does not provide reasonable assurance that it will meet the other four POs (i.e., 10 CFR 61.41 through 61.44), then DOE will likely not have met 10 CFR 61.40. Therefore, there are no specific monitoring areas (MAs) or monitoring factors for 10 CFR 61.40 in this monitoring plan.

With the exception of 10 CFR 61.43, the ability to observe and measure any direct violation of the POs will be very limited in the foreseeable future. The public will have limited and controlled access to environmental media (air or water) that could be contaminated by residual FTF waste until the federal government cedes the site. Similarly, a successor resident is expected to have low probability of directly intruding upon residual waste. Finally, while current activities could result in long-term stability concerns, major activities that will impact long-term stability, (i.e., emplacement of the site cover) will not occur for many years. Therefore, the U.S. Nuclear Regualtory Commission will rely on indirect indicators, referred to as key MAs, to ascertain DOE's ability to affect continued compliance with POs as it proceeds with closure operations over the next several decades. The key MAs, rationale for their relevance, and specific monitoring activities related to them are summarized herein.

3 MONITORING TO ASSESS COMPLIANCE WITH 10 CFR 61.41

Concentrations of radioactive material which may be released to the general environment in groundwater, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable (ALARA).

Protection of the general population from releases of radioactivity is a dose-based standard that considers potential releases of radioactivity from a low-level waste (LLW) disposal facility, such as the F-Tank Farm (FTF) facility into the general environment. These releases may cause a receptor to be exposed through direct or indirect contact with various environmental media such as soil, water, air, and plant or animal products (Figure 3-1). Direct pathways include direct radiation exposure or inhalation of buried waste residuals that may migrate to the surface. Indirect (groundwater) pathways include ingestion of crops irrigated with contaminated water, ingestion of animals or animal products exposed to contaminated water and fodder (grown in soil irrigated with contaminated groundwater), ingestion of contaminated groundwater, and incidental ingestion of soil (irrigated with contaminated water). Because FTF waste is located several meters below grade underneath a closure cap, the primary pathway of exposure of potential receptors to residual waste at the FTF disposal facility is through leaching of radionuclides into groundwater. Shielding of buried radiation by engineered barriers lowers the potential dose from direct radiation exposure. Transport of buried radioactivity from FTF components to the surface in the vapor phase also is considered a less risk-significant process. Therefore, direct radiation exposure from buried contamination and releases of radioactivity to air and subsequent transport to the surface are not a focus of the U.S. Nuclear Regulatory Commission's (NRC) staff's monitoring under 10 *Code of Federal Regulations* (CFR) 61.41. Review of air monitoring data is, however, an aspect of NRC's evaluation of 10 CFR 61.43 as it pertains to protection of members of the public, particularly during active disposal facility operations such as cleaning and grouting of the high-level waste (HLW) tanks when the risk of airborne releases are the greatest.

Because the 10 CFR 61.41 evaluation is prospective, a performance assessment (PA) analyst must select an evaluation period. However, the time period over which the evaluation should be conducted is not specified in the rule. LLW and waste incidental to reprocessing (WIR) guidance found in NUREG–1573 (NRC, 2000) and NUREG–1854 (NRC, 2007) suggests that generally a 10,000 year period of performance is sufficient to demonstrate compliance with the performance objective (PO). However, longer evaluation periods may be necessary to capture the peak dose and provide insights on facility (natural and engineered) performance for certain long-lived wastes. The 10 CFR 61.41 standard also has an ALARA component to ensure that operations and closure are optimized to achieve the lowest overall risk to members of the public, workers, and the environment.

NRC staff evaluates compliance with 10 CFR 61.41 using more recent internal dosimetry methods than available when the Part 61 rule was developed. In lieu of using whole body and individual organ dose limits specified in the 10 CFR Part 61 rule, NRC uses a single dose criterion of 0.25 mSv/yr (25 mrem/yr) total effective dose equivalent to evaluate compliance with 10 CFR 61.41. This departure from the 10 CFR 61.41 rule is explained further in NUREG–1854 (NRC, 2007) and is consistent with the "Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada" rulemaking (66 FR 55752).

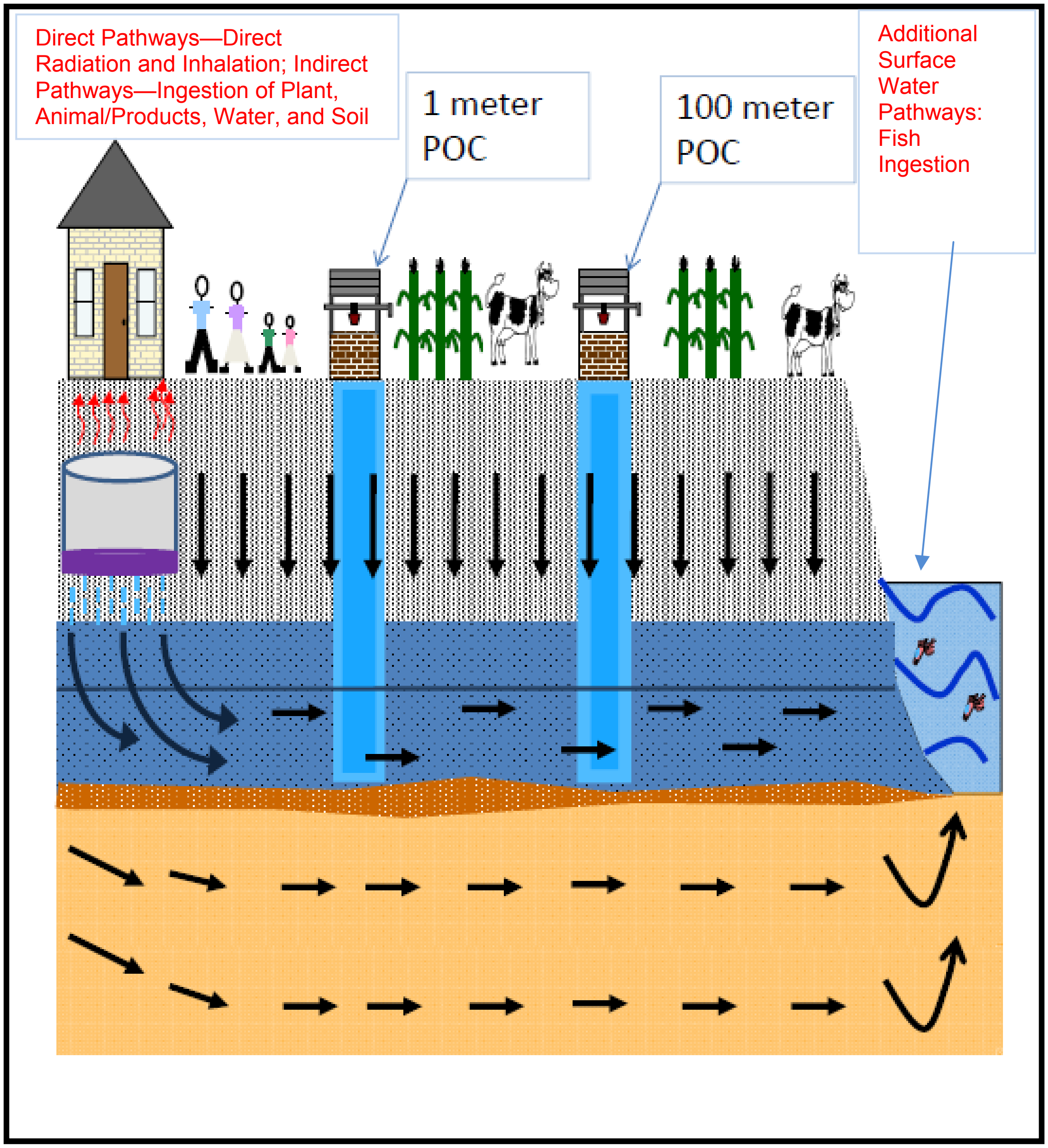

Figure 3-1. Potential Pathways of Exposure to a Member of the Public and Points of Compliance for the 10 CFR 61.41 (100 m) and 61.42 (1 m) Analyses

To determine the dose to a potential receptor, NRC also must select a point of compliance (POC). NRC guidance in NUREG–1854 (NRC, 2007) indicates that after the end of the institutional control period,[3] the receptor evaluated to demonstrate compliance with the 10 CFR 61.41 PO is assumed to be located at the point of highest projected dose beyond a 100 m buffer zone surrounding the disposal facility (see Figure 3-2 that denotes the 100 m and 1 m boundaries, the points at which the dose-based standards in 10 CFR 61.41 and 10 CFR 61.42 are assessed in the U.S. Department of Energy's (DOE) FTF PA, respectively).

[3]Before the end of the institutional control period, the point of compliance is located on the larger site boundary over which DOE maintains access control.

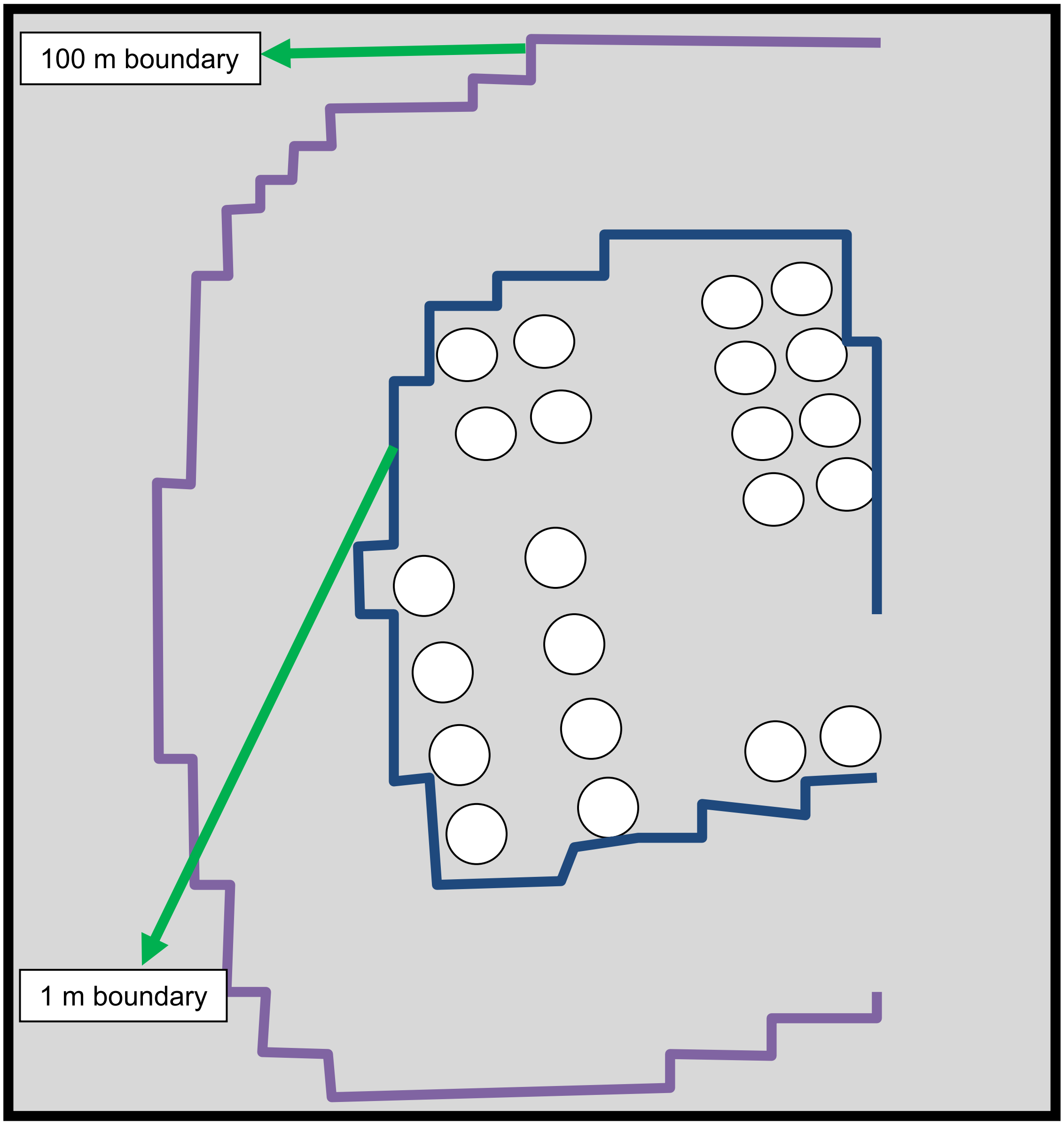

Figure 3-2. Approximate 1 m and 100 m Boundaries Where the U.S. Department of Energy Evaluates Compliance in Its PORFLOW Model Domain (Adapted from DOE, 2008, Figure 5.2-5)

Considering the specific objectives and established paradigms for assessing compliance with 10 CFR 61.41, NRC staff identified key aspects of disposal facility performance that have the largest impact on the 10 CFR 61.41 compliance demonstration based on information provided in DOE's PA. NRC staff found that several monitoring areas (MAs) are important to meeting the 10 CFR 61.41 PO. For example, the residual inventory remaining in the cleaned tanks is a good indicator of the potential risk associated with each tank (Section 3.1 on MA 1 "Residual Inventory").

However, the extent to which the inventory of key radionuclides affects facility risk also is strongly influenced by the assumed rate of release of the inventory from the tanks. Because the key radionuclides are highly concentrated in a very small volume of waste, solubility limits apply for many key radionuclides. In some cases, solubility control of the radionuclides is the single most important factor controlling release and dose. Therefore, NRC staff established waste release as a key MA (Section 3.2 on MA 2 “Waste Release”).

For both solubility and nonsolubility controlled radionuclides, releases cannot occur from the tanks until the steel liners (i.e., the tanks) fail. Furthermore, even after release from the tanks, key radionuclides must traverse the concrete basemats underneath the tanks. Because DOE assumes the concrete vaults that house the high-level radioactive waste tanks (i) provide a passive environment that drastically slows corrosion of the tanks and (ii) because the floor of the concrete vaults (i.e., tank basemats) attenuate or provide a barrier to the release of radionuclides out of the tank, NRC staff established cementitious material performance as a key MA (Section 3.3 on MA 3 “Cementitious Material Performance”).

Following release from the tanks, the final barrier to waste release is the natural environment surrounding the disposal facility. The natural environment acts as a barrier because it interacts with radioactivity leaving the tanks and causes key radionuclides to move at a slower rate than water and in some cases decreases concentrations in a down-gradient well where a potential receptor may be exposed. Dilution of key radionuclides leaching from the FTF tanks into the aquifer below also is an important natural attenuation mechanism that NRC staff will monitor. Therefore, NRC staff created MA 4 “Natural System Performance” as a key MA (Section 3.4). Figure 3-3 provides details regarding the assumed capabilities of each FTF barrier described above in limiting or mitigating long-term releases from the closed FTF HLW tanks.

NRC staff also established MAs to address more routine or longer-term monitoring activities including the following:

- MA 5 “Closure Cap Performance”
- MA 6 “Performance Assessment Maintenance”

Although NRC staff concluded that the FTF closure cap is a redundant barrier[4] in DOE’s FTF PA, NRC staff nonetheless established MA 5 “Closure Cap Performance” as an MA for FTF because staff concluded that in certain cases, the FTF closure cap could be important to mitigating risk from the disposal facility and in maintaining doses ALARA. Therefore, NRC staff created MA 5 as an MA, given the potential for the closure cap to serve as an important barrier that may help ensure compliance with each of the 10 CFR Part 61, Subpart C, POs. Section 3.5 contains additional details on the monitorin factor (MF) related to the closure cap.

NRC staff binned all comments and recommendations from its TER (NRC, 2011) that were of relatively lower risk-significance or required long-term action to address in a single category, MA 6 “Performance Assessment Maintenance.” The MA 6 term “Performance Assessment

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[4]NRC staff concluded that DOE’s reference or best-estimate PA case shows the FTF closure cap is a redundant hydraulic barrier as other, more robust hydraulic barriers such as the steel liners and tank grout used to fill the cleaned tanks are present and expected to outperform the closure cap for longer periods of time under most scenarios, including the reference case used by DOE in its FTF PA. However, it is important to note that the closure cap is the only barrier assumed to provide long-term infiltrating-reducing capabilities, albeit at modest levels. Figure 3-4 shows barriers to timing of tank farm releases in DOE’s reference case. The dark blue barrier represents the closure cap that is assumed in DOE’s PA to be fully or nearly fully effective for less than 1,000 years before its performance drops off rapidly compared to the light blue (tank grout) or green (steel liner) barriers that last in most cases for tens of thousands of years following disposal facility closure. However, it is important to note that after a few thousand years, infiltration through the closure cap is assumed in DOE’s PA to stabilize to a constant rate of approximately 30 cm/yr [12 in/yr] for all time, less than the background infiltration rate of 37 cm/yr [15 in/yr], while no other barrier serves to permanently reduce infiltration.

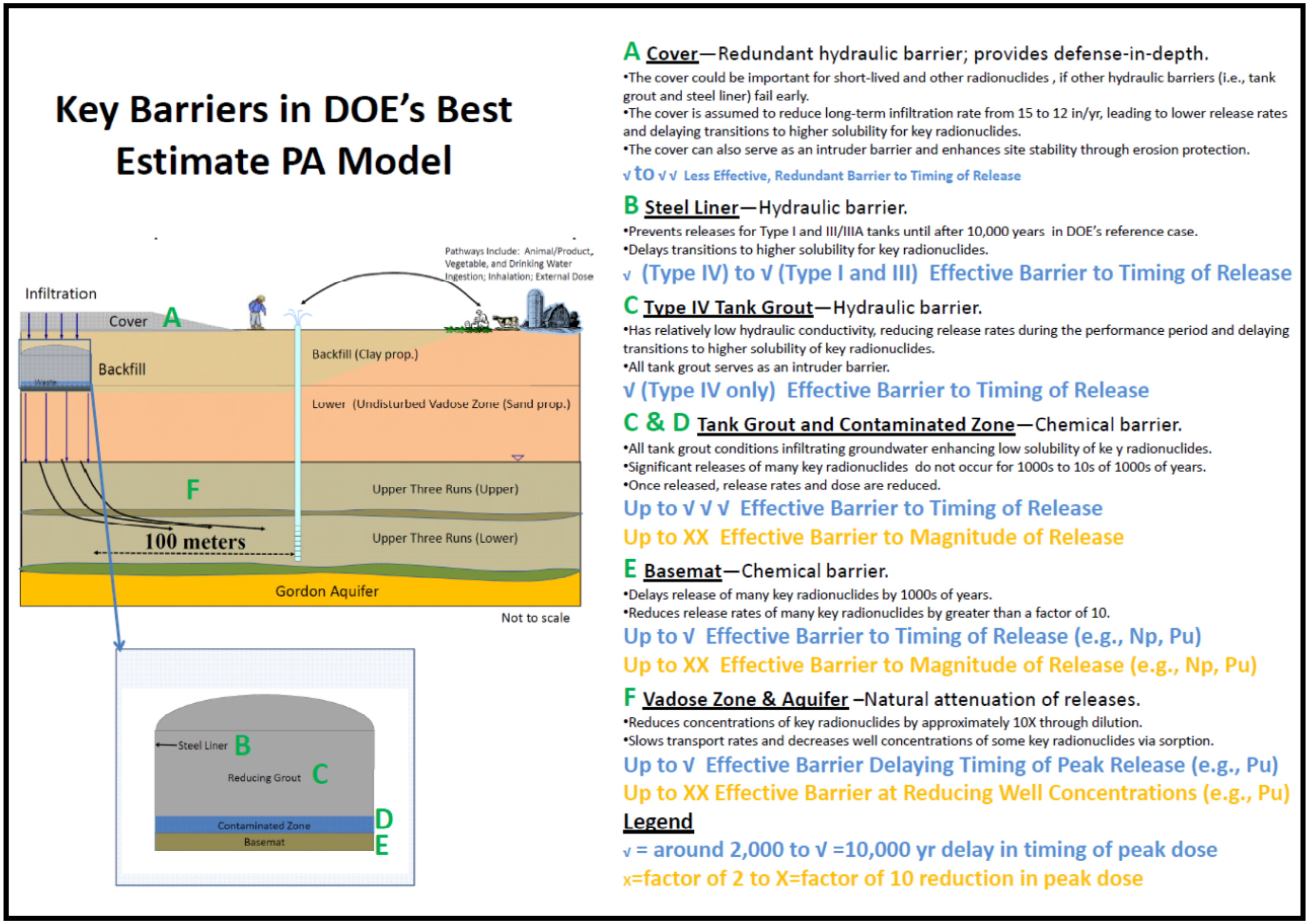

Figure 3-3. F-Tank Farm Barriers in the U.S. Department of Energy's F-Tank Farm Performance Assessment Reference Case

Maintenance" should not be confused with a similar, but broader, term used by DOE to describe all of the short-term and longer-term activities it plans to undertake to maintain its PA, including planned research and tank characterization activities, the results of which may be reflected in a future PA revision. In other words, DOE's PA maintenance plan encompasses all activities NRC staff might discuss under each key MA, as well as lower priority activities NRC staff discusses under MA 6 "Performance Assessment Maintenance." In contrast, only those items of lower risk-significance or longer term PA maintenance activities are discussed by NRC staff under MA 6 "Performance Assessment Maintenance."

3.1 MA 1 "Inventory"

Inventory for key radionuclides is important to the compliance demonstration because inventory is linearly related to dose for those radionuclides that are not solubility limited. Even for key radionuclides that are solubility controlled, in some cases (e.g., when solubility control is not the primary barrier to release from the engineered disposal system) doses also can be very sensitive to inventory. This is true because with higher inventory more activity can accumulate in a down gradient barrier (e.g., concrete basemats underneath the tanks that may control release for certain key radionuclides). For those radionuclides that are solubility limited, inventory also can be important from a mass depletion perspective. For example, the inventory of a key radionuclide could be released at very low concentrations over a long period of time, such that little to no activity remains when the solubility of the key radionuclide increases to risk-significant values. In these cases, a higher inventory could lead to significantly higher peak releases and dose from the engineered system than would occur from a lower inventory. Inventory can be very risk-significant for both solubility-controlled and nonsolubility controlled constituents and, therefore, is listed as an MA for FTF.

Based on DOE's PA, the key risk drivers under 10 CFR 61.41 for the FTF over longer evaluation periods are as follows: Technetium (Tc)-99, Plutonium (Pu)-239, Neptunium (Np)-237, and Radium (Ra)-226. Type IV Tank 18 contains the largest inventory of Pu-239 in FTF, leading to a peak dose of approximately 5 mSv/yr [500 mrem/yr] within 40,000 years in DOE's reference or best-estimate PA case[5]. Type I tanks contain the highest assumed inventory of Tc-99, leading to the overall peak dose of approximately 6 mSv/yr [600 mrem/yr] after 20,000 years in DOE's reference or best-estimate PA case. All tanks contain risk-significant quantities of Np-237 or Am-241 (parent of Np-237) that could lead to doses similar to the 10 CFR 61.41 standard evaluated at 0.25 mSv/yr [25 mrem/yr]. The key radionuclide Ra-226 is a significant but lower-risk, highly radioactive radionuclide (HRR) compared to Tc-99, Pu-239, and Np-237 in DOE's reference case. Ra-226 is produced at the FTF via radioactive decay of its parents, Th-230, U-234, and Pu-238. The highest concentration of Ra-226 parents is found in Tank 18, although other tanks also have significant quantities of Ra-226 predecessors.

Because facility risk is sensitive to key radionuclide inventory, in most cases a threshold inventory exists below which a key radionuclide ceases to be important to the compliance demonstration. For some key radionuclides (e.g., relatively long-lived and mobile), it may be more cost effective to remove additional activity from the tanks than it would be to provide additional information to support a key modeling assumption relied on for compliance. In fact,

[5]The FTF PA, Rev. 1 (SRS-REG-2007-00002, Rev. 1) dose estimates were updated in Tanks 18 and 19 special analyses (SRR-CWDA-2010-000124, Rev. 0). A range of dose values was included in the special analyses using updated solubility and sorption data. Some values were similar to previous estimates, while other values were significantly below previous estimates.

NRC staff indicated in the request for additional information (RAIs) and in its technical evaluation report (TER) (NRC, 2011) its position that it would be difficult for DOE to provide supporting information for the assumption that 100 percent of Tc is co-precipitated with iron mineral phases in the tank waste. In response to NRC staff's RAIs, DOE provided additional information from Tanks 5 and 6 to support a significantly lower inventory estimate for Tc-99 in Type I tanks. Until then, Tc-99 had been regarded as the single most risk significant radionuclide for FTF over longer periods of performance in DOE's base case analysis, owing to its relatively high mobility in the environment. If DOE can show the residual Tc-99 inventory is below levels of concern, then no additional support for the iron co-precipitation model for Tc will be needed. NRC staff will monitor progress on Type I tank closures to ensure the inventory of Tc-99 is reduced to non-risk-significant levels. If Tc-99 inventory cannot be reduced to these low levels, then other barriers to waste release for Tc-99 will become increasingly important. Table 3-1 indicates NRC staff's current thinking that inventory is the likely one of the most effective ways of providing support for the 10 CFR 61.41 compliance demonstration with respect to Tc-99 and Np-237 doses. It is important to note that the inventory of Am-241, parent to Np-237, should be considered in determining whether or not Np-237 will be produced at risk-significant levels over time.

<u>NRC Monitoring Under MA 1 "Inventory"</u>

As listed in Appendix A and documented in more detail in NRC's TER (NRC, 2011), NRC staff will consider the following MFs related to inventory that are considered important to meeting the 10 CFR 61.41 PO:

- Final Inventory and Risk Estimates.

The following factors support development of the final inventory (e.g., sampling and volume data are used to estimate a final inventory) and also are listed as MFs under MA 1 "Inventory."

- Waste Sampling,
- Waste Volume, and
- Ancillary Equipment Inventory.

The following factor, related to the final tank inventory, is important to meeting ALARA criteria in 10 CFR 61.41 and will, therefore, be listed as an MF under MA 1 "Inventory":

- Waste Removal As It Pertains to ALARA.

3.1.1 Monitoring Factor 1.1: Final Inventory and Risk Estimates

DOE has committed to sample each tank following waste retrieval activities. During the monitoring period, NRC staff will review special analyses performed for tanks as they are cleaned. NRC staff will assess the degree to which DOE demonstrates the FTF will meet the POs with the new projected radionuclide inventories, if inventory exceeds the predicted inventory used to support the determination. NRC staff will assess the degree to which DOE's special analyses evaluate uncertainty in the revised inventory. NRC staff should independently verify whether the change in inventory is likely to significantly affect the dose to a hypothetical receptor {a 0.25 mSv/yr [25 mrem/yr]} limit to a member of the public under 10 CFR 61.41 or an applied 5 mSv/yr [500 mrem/yr] limit to an intruder under 10 CFR 61.42}. NRC staff should review the reasonableness of DOE's approach to developing inventory multipliers used in the uncertainty analysis. NRC staff will review these special calculations for each cleaned tank to ensure that PA is sufficiently bounding. This factor can be closed following NRC review of the last tank or equipment specific special analysis prepared by DOE for FTF.

Table 3-1. Relative Risk and Contributions of F-Tank Farm Barriers to Reducing Risk for Three Key Radionuclides (Tc, Pu, and Np)*

		Tc	Pu	Np	Notes
1	Total Barrier Performance Needed (Function of Inventory)†	6‡ (Type 1)	9 (Type IV, Tank 18)	6‡ (Type I)	Factor reduction in concentration needed to meet the 10 CFR 61.41 dose standard. The tank/type producing the highest dose for each key radionuclide is provided in parentheses.
	Engineered System				
2a	Solubility Control	0‡	2‡	1 to 2‡	Final solubility
2b		(9 to 11)§	(9 to 11)§	(5 to 6)	Initial solubility
3	Basemat Attenuation (Sorption)	<1	2§	2§	Very important for Pu and Np. Can compensate for solubility.
4	Near-Field Diffusion or Dispersion‡	2^	1§	1§	Additional reduction in concentration due to upward diffusion into tank grout, large cell size, or dispersion.
	Natural System				
5	Aquifer Dilution	1	1	1	Based on simple aquifer mixing model; comparison of concentrations between vadose zone and saturated zones; and between source and POC.
6	Sorption	<<1	1‡	<<1	
7	Additional Dispersion to POC	1-2§	1§	1§	Pu sorption can compensate for other barrier underperformance.
8	Total Barrier Performance	5	8	6 to 7	Sum of rows 2a, 3-7.
9	Calculated Safety Margin	-1	-1	0 to 1	Difference Between Row 8 and Row 1.

Tc–Technetium, Np–Neptunium, Pu–Plutonium
*All values in the table are approximate (order of magnitude). Values only are intended to provide relative information on the contributions of various barriers in DOE's FTF PA and are not expected to be exact. Many of the values for the various barriers were estimated based on tracking the concentrations of the three key radionuclides from the contaminated zone to the point of compliance in DOE's PORFLOW models for the tank/type listed in Row 1.
†The "total barrier performance needed" is calculated by assuming the entire FTF tank inventory is located in the pore water of the contaminated zone. While virtually impossible, assuming the total inventory is available to a potential receptor is necessary to provide a starting point from which to evaluate the contributions of various barriers to reducing risk and to gauge the relative residual risk associated with each key radionuclide listed based on inventory and groundwater pathway dose conversion factor (measure of risk) of each radionuclide. The contaminated zone is assumed to be one inch thick with a porosity of 0.27. For example, a value of "6" for Tc in the first row corresponds to a factor of 10^6, or 1,000,000, the factor by which the concentration in the waste zone needs to be reduced to produce a groundwater concentration at the point of compliance equivalent to 0.25 mSv/yr [25 mrem/yr] total effective dose equivalent based on DOE biosphere modeling in the FTF PA.
‡Most tractable
§Potentially optimistic
‖Dispersion is used in a broad sense to describe diffusion, numerical, and physical dispersion in DOE's PA models. Because Tc is ultimately assumed to be highly soluble and mobile in DOE's PA model, almost all the attenuation of Tc is due to dilution and dispersion. No solubility control is assumed for Tc upon transition to the final chemical state.

3.1.2 Monitoring Factor 1.2: Residual Waste Sampling

To accurately estimate the post-cleaning inventory that will be stabilized in FTF tanks, DOE must sample and analyze the residual waste concentration in each tank after it is cleaned, as well as characterize the solids density and estimate residual waste volumes. NRC staff will review sampling and analysis plans developed for each tank, as they are cleaned.

NRC's technical review of sampling and analysis plans should include, but may not be limited to, the following considerations:

- Consideration of intratank waste variability that is important to the sampling design, including the basis for assumptions regarding homogeneity and the number of samples to be collected.

- Use of floor concentration samples for assigning residual waste inventory for tank walls.

- DOE's support for assumptions regarding normality of radionuclide concentration when developing deterministic and probabilistic inventory parameters.

- Sampling of HRRs or basis for removal of HRRs from the list of radionuclides to be sampled.[6]

In addition to review of sampling and analysis plans, NRC staff also will conduct its own independent assessment to verify the list of HRRs in DOE's assessment is complete. If additional HRRs are identified, NRC staff will meet with DOE to resolve the discrepancies in the list and suggest actions, as appropriate, that DOE could take to ensure that FTF risks are appropriately assessed and managed. Technical review efforts under this MA should be coordinated with onsite observations of waste sampling to evaluate whether samples are being collected in accordance with sampling analysis plan and the quality of data is sufficient to meet data quality objectives.

This MF can be closed following review of the last sampling and analysis plan for an FTF tank and following the last planned onsite observation of sampling of an FTF tank (may occur prior to the last tank or ancillary equipment being sampled).

3.1.3 Monitoring Factor 1.3: Residual Waste Volume

Residual waste volume is multiplied by density and radionuclide concentrations to estimate the residual inventory and is, therefore, important to development of the final inventory. As documented in its TER (NRC, 2011), NRC staff noted there is significant uncertainty in DOE's current material mapping approach used for volume estimation. NRC staff recommended DOE explore methods to improve the process by which it estimates residual waste volumes and

[6] In its TER (NRC, 2011), NRC staff recommended DOE continue to characterize samples for radionuclides that are important to risk. The HRR list is used to target radionuclides for waste characterization. Thus, the HRR list is important for determining accurate inventories for the FTF and adequately assessing risk. DOE eliminated certain radionuclides from the initial HRR list based on Tank 18 and 19 inventories (Cs-135, U-233, Th-229, and Ra-226). Unless DOE can show that the inventories will not be significantly different for other tanks DOE should continue to characterize samples for these radionuclides. NRC staff will review sampling and analysis plans to ensure that all HRRs are sampled or a basis for exclusion of an HRR is provided.

associated uncertainty, including evaluation of the costs and benefits of alternative technologies available for mapping. For example, NRC noted in its TER (NRC, 2011) the following potential improvements:

- DOE could improve the process by which it estimates volume in areas of cleaned tanks where relative objects used to make depth comparisons are not available. For example, in certain areas in Tanks 18 and 19, which could not be accessed by the Mantis and could not be mapped due to lack of relative objects for depth comparison, the mapping team applied weights based on other areas that were deemed similar. In the case of Tanks 18 and 19, it was not clear if DOE could have obtained access to certain areas of the tanks by removing obstacles or creating new points of access. DOE also could have more clearly described the process.

- DOE also could improve the method of characterizing uncertainty and variability in depth of waste across the tank floor. For tank volume in Tanks 18 and 19, DOE fit a normal distribution to the data. NRC staff notes that artificially fitting a normal distribution for the volume may not properly take into account the variability of the depths of residual material on the tank floor. Alternatively, DOE also could have assessed the uncertainty by looking at the variability in the depths estimated through material mapping and developing distribution models based on the specific sample population (weighted for the area of each sample).

In lieu of improving the method by which DOE estimates residual waste volume, DOE could manage inventory uncertainty with conservative estimates (i.e., volume estimates that clearly err on the side of higher values).

DOE indicates its intent to improve the method of estimating residual volumes in its PA Maintenance Plan (SRR–CWDA–20012–00022). NRC staff will monitor DOE's progress in this area. NRC staff also will attempt to observe DOE's use of video and photographic records to develop residual waste volumes during an onsite observation. This factor will be closed once NRC staff concludes DOE has taken steps to improve the process by which it estimates residual volumes or shows that DOE has appropriately managed volume uncertainty. The factor may be re-opened if NRC staff identifies issues with DOE's approach to developing or consideration of uncertainty in volumes estimates.

3.1.4 Monitoring Factor 1.4: Ancillary Equipment Inventory

The low risk significance of ancillary equipment to meeting the 10 CFR 61.41 PO is predicated on the assumed inventory for key radionuclides in DOE's PA. Therefore, the inventory for ancillary equipment should be confirmed to support NRC staff's understanding of the low risk significance of these FTF components. DOE indicated, in response to NRC comment (SRR–CWDA–2009–00054, Rev. 0), its intent to verify PA assumptions regarding transfer line inventories consistent with Section 8.2, "Further Work" in DOE's PA (SRS–REG–2007–00002, Rev. 1). NRC staff will discuss with DOE its schedule for characterization of transfer lines to ensure conclusions regarding the relatively low risk estimates for transfer lines are confirmed. Additionally, transfer line inventories are important for the intruder analysis because DOE assumes an intruder can more easily access the residual inventory in a transfer line than in a tank. Transfer line inventories are discussed in more detail in Chapter 4, which includes information on MFs related to assessing compliance with the 10 CFR 61.42 PO.

This MF can be closed once NRC staff concludes that DOE characterization has confirmed the low risk of ancillary components.

3.1.5 Monitoring Factor 1.5: Waste Removal (As It Pertains to ALARA)

In the final FTF waste determination (WD), DOE cites its ability to meet the the Ronald Reagan National Defense Authorization Act for Fiscal Year 2005 (NDAA) criteria "removal of HRRs to the maximum extent practical" as the primary means by which it meets the ALARA criteria in 10 CFR 61.41. NRC will evaluate removal to the maximum extent practical for each cleaned tank to ensure DOE disposal actions are consistent with ALARA criteria. NRC staff will assess DOE compliance with ALARA objectives through review of DOE documentation completed in conjunction with the federal facility agreement closure process. As provided in NRC guidance [NUREG–1854 (NRC, 2007)], NRC staff also should pay special attention to the distribution of residual inventory in the cleaned tanks to ensure compliance with ALARA (e.g., removal of waste from areas susceptible to preferential pathways, such as tank walls).

This MF can be closed once all FTF tanks are cleaned and NRC staff has reviewed DOE documentation of removal to the maximum extent practical.

Closure of Monitoring Factors Related to MA 1 "Inventory"

NRC staff expects that MFs related to inventory will be closed after tank cleaning activities and subsequent post-cleaning sampling activities are completed for FTF tanks.

3.2 MA 2 "Waste Release"

Importance of MA 2 "Waste Release"

In the PA reference (or best-estimate) case, DOE assumes for many key radionuclides that concentrations released from the tanks are limited to low values for long periods of time. Key radionuclide concentrations in the waste zone are limited through solubility control and the imposition of solubility (or concentration) limits. If waste zone concentrations are limited to low values, then exposure to a member of the public that may result from use of contaminated groundwater at the points of compliance (maximum concentrations on the 1 or 100 m boundaries) also will be limited. Solubility (or waste release) assumptions are, therefore, important to DOE's demonstration of compliance with the 10 CFR 61.41 PO and are considered a key component of NRC staff's monitoring program.

The solid phases that are assumed to be present in the waste (or contaminated) zone dictate the solubility (or concentration) limits of key radionuclides. The key radioelements that are (i) important to dose and (ii) sensitive to solubility limits are Tc, Np, and Pu. Solubility limits for these elements are modeled, in DOE's PA, for (i) pure phases consisting only of the key radionuclide itself as a precipitated solid and (ii) in the case of Tc and Pu, as co-precipitated[7] with iron-bearing mineral solids in the waste residue. NRC staff will, therefore, focus on these three elements, their assumed solubility-limiting phases, and associated solubility limits during FTF monitoring under MA 2.

[7]DOE uses the term "co-precipitated" in a broad sense to refer to the incorporation of key radionuclides into a solid iron mineral (rather than being a pure solid comprised of just that key radionuclide). The solubility of the key radionuclide is assumed to be controlled by the solubility of the iron mineral.

In addition to the solubility limiting phases and associated solubility limits for key radionuclides, assumptions regarding the length of time that key radionuclides remain in a low solubility phase also are important to the compliance demonstration from a timing perspective (i.e., DOE relies on the two largest key radionuclide peak doses of approximately 5[8] and 6[9] mSv/yr [500 and 600 mrem/yr] from Pu-239 and Tc-99, respectively, occurring after the 10,000 year compliance period because the peak doses from Pu-239 and Tc-99 are both greater than the PO of 0.25 mSv/yr [25 mrem/yr]. DOE assumes groundwater infiltrating the tank system will be conditioned by the tank grout used to stabilize the waste residuals through which it must first flow[10] to get to the contaminated zone. Conditioning is assumed to occur for thousands to tens of thousands of years (purple barriers in Figure 3-4). Conditioning of the groundwater through its interactions with tank grout is important because DOE assumes the chemical properties of the conditioned groundwater in its models to help maintain the low solubility of key radionuclides in the contaminated zone. It is not until the beneficial tank grout components, which help maintain the low solubilities, are depleted through their interactions with infiltrating groundwater that Eh[11] increases and pH[12], decreases allowing the most risk-significant radionuclides at FTF to be released at higher solubilities and rates in DOE's reference PA case. Therefore, the longevity of the chemical conditioning of infiltrating groundwater that maintains low solubility is a function of both (i) the flow path of water movement through the grout mass (e.g., bypass flow through preferential pathways with minimal contact of water with grout or matrix flow through the grout monolith with maximum contact of water with the grout) and (ii) the geochemical interactions between the water and the contacted grout mass. The assumptions regarding the movement of infiltrating water through the grout mass are discussed further in MA 3 "Cementitious Material Performance," Section 3.2. Assumptions regarding the longevity of reducing conditions and high pH that are based on DOE's geochemical modeling are the subject of this MA and are discussed in more detail under MF 2.2.

[8] DOE provided an updated dose projection around 2.5 mSv/yr [250 mrem/yr] for Pu-239 in Tanks 18 and 19 special analyses (SRR-CWDA-2010-000124, Rev. 0), "conservative Eh" case.

[9]As documented in its TER, DOE has provided information to support a significantly lower inventory for Tc-99 at FTF. Therefore, the peak dose from Tc-99 is likely over-estimated.

[10]This is true for DOE's reference or best-estimate PA case. However, in an alternative conceptual model, not explicitly modeled by DOE, the groundwater table may periodically rise above the bottom of the tanks and lead to limited or unconditioned release of key radionuclides from the contaminated zone. NRC staff discusses this alternative conceptual model for waste release under MA 3 "Cementitious Materials Performance."

[11]Eh is a measure of oxidation-reduction potential or electron activity (or concentration). Eh is measured in millivolts and varies from approximately -500 to +800 in natural environments. Many key radionuclides are less mobile or less soluble at lower values of Eh or what is referred to as "reducing conditions." Solubility of many key radionuclides increases when Eh value rises (e.g., Pu solubility increases significantly when Eh rises above a value of around +0.45 volts in DOE's updated solubility modeling (Denham, 2012) or when the system becomes "oxidized"). Oxidation signals the transition from a chemical state that DOE refers to as Reduced Region II to a chemical state referred to as Oxidized Region II. The transition from reduced to oxidized conditions is marked in Figure 3-4 by the vertically oriented green-dashed line.

[12]Measure of hydrogen ion activity (or concentration) or measure of acidity. The pH is a unitless number calculated as the negative of the log of the hydrogen ion concentration that is measured in mol/L. The pH of the Upper Three Runs aquifer at SRS ranges from 5.2 to 7.7 (Prikryl and Pickett, 2007). Undegraded cementitious materials tend to increase pH to values as high as 12.5. In DOE's reference (or best-estimate) case, a decrease in pH to approximately eight or nine generally leads to increases in solubility limits or releases from the tanks. When pH decreases to that value, a chemical transition is assumed to occur from what DOE refers to as Oxidized Region II to Oxidized Region III. The Eh-based chemical transition discussed in the preceding footnote occurs prior to the pH-based chemical transition, with the two transitions delineating the three chemical states, with a solubility specified for each key radionuclide and chemical state, which DOE assumes in its PA.

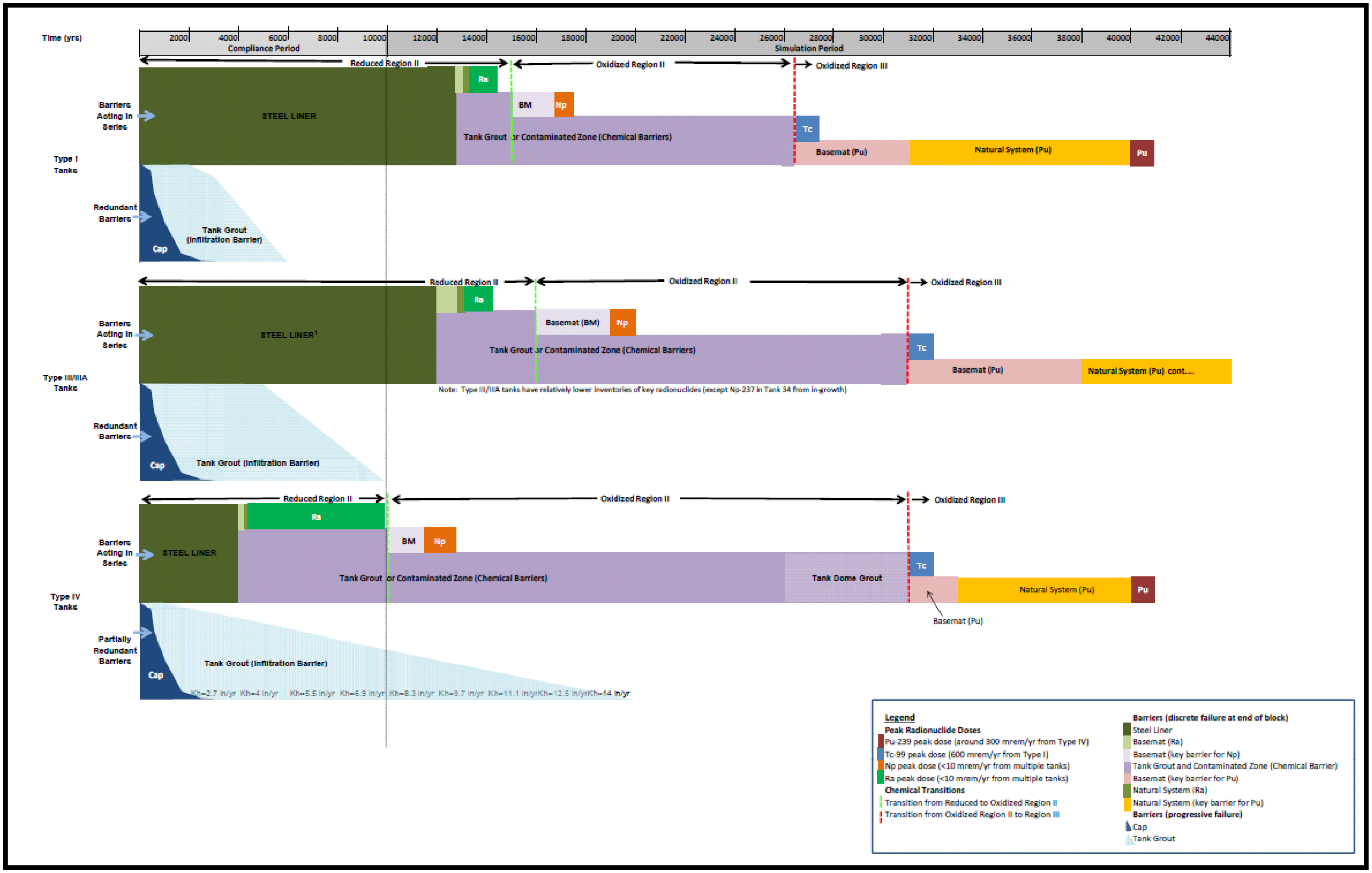

Figure 3-4. Barriers to Timing in the U.S. Department of Energy's F-Tank Farm Reference (or Best Estimate) Performance Assessment Case

NRC Monitoring Under MA 2 "Waste Release"

As listed in Appendix A and documented in more detail in NRC's TER (NRC, 2011), NRC will consider the following MFs related to waste release that are considered important to meeting the 10 CFR 61.41 PO:

- Solubility Limiting Phases/Limits and Validation.

Due to DOE's reliance on timing of peak dose to demonstrate compliance, NRC staff also will monitor the following factor, which is considered necessary for DOE to demonstrate compliance with the 10 CFR 61.41 PO:

- Chemical Transition Times and Validation.

More detailed discussion regarding NRC's MFs related to waste release is available in Appendix C.

3.2.1 Monitoring Factor 2.1: Solubility Limiting Phases/Limits and Validation (Applies to Tank 18, May Apply to Other Tanks Later)

Given its importance to the timing and magnitude of peak dose, in its TER, NRC staff recommended DOE conduct waste release experiments to increase support for key modeling assumptions related to (i) chemical forms of key radionuclides in residual wastes and (ii) expected solubility of key radionuclides under a range of environmental or service conditions that the contaminated zone is expected to be exposed to over time.

For Tank 18, which has been cleaned and was scheduled for near-term closure in calendar year (CY) 2012, NRC continues to recommend that DOE design and perform waste release experiments using actual tank residual samples as soon as practical. DOE staff should discuss its plans with NRC to ensure experiments are designed to optimize their potential usefulness in supporting the 10 CFR 61.41 compliance demonstration. This monitoring activity is considered to be the highest priority by NRC staff at this time from both a timing and importance perspective. Furthermore, as indicated in Table 3-1, NRC staff thinks that in addition to being one of the most important barriers in the FTF PA, determining the solubility of Pu is expected to be one of the more tractable key technical issues. Given its importance to Tank 18 risk and overall tank closure, DOE also should consider performing solubility experiments for Np-237 at this time. Although NRC staff did not identify any issues with DOE's assumed Np-237 solubilities, DOE has not provided sufficient support for the assumed level of performance of the basemats in its FTF PA. DOE also assumes lower solubilities for Np-237 in its H-Area Tank Farm (HTF) PA compared to those assumed in the FTF PA, and if supported through experimentation, could alleviate the burden of providing additional support for other Np-237 barriers, such as the vault basemats. Table 3-1 shows the importance of the basemat in meeting the 10 CFR 61.41 PO. If the basemat does not perform as well as assumed in DOE's reference of "best estimate" case, data on solubility control may assist in demonstrating that POs can be met.

For tanks that have not been cleaned, DOE should consider the effects of reagents (e.g., oxalic acid) used to remove radionuclides from the tank residue, including formation of new compounds that may alter leachability of key radionuclides. Execution of this monitoring activity may be contingent on results of other analyses. For example, final Tc-99 inventories in Type I tanks, as described in Section 3.1, may determine the need for Tc-99 waste release experiments.

This MF can be closed once DOE provides experimental support for the assumed solubilities of key radionuclides relied on for performance. The results of near-term waste release experiments may inform the extent to which additional recommendations made in NRC's TER (NRC, 2011) would need to be implemented by DOE. Should the results of the experiments indicate less than favorable performance, NRC staff expects DOE to assess the impact of the results on the PA. NRC staff also will assess the need for additional experiments, data collection, and modeling to provide support for key barriers in DOE's PA that might serve to mitigate underperformance of chemical barriers. If the results of the experiments show that key radionuclides are strongly retained in the residual waste, NRC staff expects that in addition to this MF, other MAs or MA components will become less important and can be closed.

3.2.2 Monitoring Factor 2.2: Chemical Transition Times and Validation

DOE relies on barriers that delay the timing of peak dose to demonstrate compliance with the POs in 10 CFR 61.41, therefore, PA assumptions regarding the timing of transition of key radionuclides to higher solubility phases are important to the FTF compliance demonstration. DOE relies on geochemical modeling to estimate the time at which two key chemical transitions take place: (i) the transition from reduced to oxidized conditions reflected in an increase in Eh (see bright green, vertically oriented dashed lines in Figure 3-4), and (ii) the transition from a relatively high to a relatively low pH (see red, vertically oriented dashed lines in Figure 3-4) as the cementitious materials continue to degrade over time. In its TER (NRC, 2011), NRC staff discussed concerns with the geochemical modeling results, which may be attributable to assumptions such as (i) the characteristics of the infiltrating groundwater, (ii) the solid phases that comprise the tank grout, (iii) uncertainties in the thermodynamic data used in the modeling, or (iv) assumptions regarding the ability of grout components to react with and condition infiltrating groundwater and the residual waste.

As part of this MF, NRC staff also will evaluate the efficacy of DOE's use of two chemical transitions, three chemical states, and no more than three solubilities for each key radionuclide with solubility changes assumed in DOE's PA to occur at the same time for each key radionuclide for a given tank type. It may be more reasonable to assume that solubility of each key radionuclide has a unique sensitivity to Eh and pH, making it difficult to make generalizations about the manner in which solubility changes over time. This assumption is important because the timing of transition to higher solubility and releases may be critical to DOE's compliance demonstration, as indicated above. The adequacy of DOE's approach to modeling solubility changes will be evaluated through NRC review of the literature, DOE-generated geochemical modeling, or through independent geochemical modeling.

NRC staff also may observe DOE experiments related to this MF in conjunction with an onsite observation at the FTF. This MF can be closed when (i) DOE shows that chemical transition times are no longer important to its compliance demonstration (i.e., predicted dose is less than the dose standards for all time) or (ii) DOE provides adequate (e.g., experimental validation) support for its assumptions regarding chemical transition times.

Closure of the Group of Monitoring Factors Related to MA 2 "Waste Release"

The MF regarding chemical transition times can be closed when DOE completes experiments to study the evolution of pH and Eh in the tank grout over time to provide more accurate estimates of chemical transition times to higher solubility chemical conditions. Alternatively, this MF can be closed if DOE can provide support that the highest solubility for each key radionuclide developed under MF 2.1, under any relevant geochemical condition will not lead to an exceedance of the 10 CFR 61.41 PO (i.e., DOE no longer relies on timing of the peak dose to demonstrate compliance) or adequate support for other barriers relied on to delay the timing or reduce the magnitude of peak dose for key radionuclides is generated to demonstrate compliance.

Depending on the results of initial waste release experiments and other factors (e.g., expected final inventories for Tc-99 in Type I tanks), the factors in this MA can be closed in the short-term following Tank 18 waste release experiments. Likewise, if closed, NRC could reopen the MFs in this MA as additional information is obtained on expected final tank inventories or the performance of other important barriers.

3.3 MA 3 "Cementitious Material Performance"

Importance of MA 3 "Cementitious Material Performance"

As illustrated in Figure 3-4 (see dark green barrier), the steel liners (or tanks) serve as an important barrier significantly delaying the timing of releases from FTF tanks for thousands to tens of thousands of years. In the case of Types I and III/IIIA tanks, DOE assumes the tanks do not fail until after the 10,000 year compliance period. The longevity of the steel liners is directly related to PA assumptions regarding the capability of the concrete vaults, which house the steel liners, to provide an effective barrier to fluid flow, thereby minimizing the transport of corrosive agents such as chloride, oxygen, and carbon dioxide to the surface of the steel liners. Therefore, NRC staff considers assumptions regarding the hydraulic performance of the concrete vaults under conditions of both infiltrating water from above or flooding groundwater from below an important component of DOE's compliance demonstration. Type IV tanks at FTF are particularly susceptible to early corrosion due to the fact that the tanks (i) have a thin layer of concrete applied using a technique known as Shotcrete, (ii) do not have an annulus between the "Shotcrete" and liner, (iii) do not have a tank top, (iv) have bottoms located in close proximity to the water table, (v) have experienced groundwater in-leakage in the past, and (vi) have the thinnest steel liners.

As discussed in MA 2 "Waste Release," DOE relies on the timing of peak dose occurring after the 10,000 year compliance period to meet the 10 CFR 61.41 PO in its reference (or best estimate) PA case[13]. Therefore, any barrier that delays the timing of peak dose is important to DOE's compliance demonstration for the FTF. The reducing tank grout and contaminated zone chemical barriers (represented by a single purple barrier in Figure 3-4) are two of the most effective barriers in DOE's FTF PA in delaying the timing of the peak dose. Chemical transition times are directly dependent on the nature of water flow through the grouted tanks and on the likelihood and frequency of tank flooding due to water table rise. For example, NRC staff has technical concerns related to the potential for: (i) groundwater to bypass or have minimal contact with the reducing tank grout as a result of flow via preferential pathways such as cracks or shrinkage gaps and (ii) water table rise above the tank bottoms.[14] NRC staff is concerned

[13]Type I tanks and Tank 18 are the sources of exceedance of the 10 CFR 61.41 standard in DOE's FTF PA. DOE thinks the Type I tank inventories of Tc-99 that led to the exceedance were overestimated in the FTF PA. Updated special analyses show the peak dose from Tank 18 may be above or below the 0.25 mSv/yr [25 mrem/yr] dose standard, depending most significantly on assumed solubility of Pu-239. NRC staff will evaluate the updated modeling under MA 2.

[14]Water table rise is especially important for Type IV tanks, which have bottoms located at or near the water table and for Type I tanks (Amidon, et al., 2012).

because these scenarios could lead to a situation where relatively oxidized and acidic groundwater has minimal contact with the tank grout that DOE's PA assumes will condition the groundwater to higher pH and lower Eh, thereby maintaining the low solubility of key radionuclides in the contaminated zone. If the infiltrating groundwater is not well-conditioned, key radionuclides may have higher solubility and be released at significantly higher concentrations, much earlier in time. In fact, the peer review group tasked by DOE to review DOE's Pu solubility modeling indicated that flow through cracks in the grout should be expected (Cantrell, et al., 2011). Therefore, NRC staff will monitor DOE's FTF PA assumptions related to the nature of water flow into the contaminated zone, including assumptions regarding the extent to which in-tank water is conditioned by the tank grout, the timing of chemical transitions, and the magnitude of key radionuclide releases and dose.

Additionally, because preferential flow through the tank grout is a strong function of the extent to which FTF tank grout shrinks and cracks, NRC staff also will monitor DOE FTF PA assumptions regarding shrinkage and cracking. Specifically, NRC staff will monitor DOE's efforts to minimize tank grout shrinkage through additional shrinkage compensating admixtures. Shrinkage of grout away from tank walls and intratank components may lead to formation of preferential flow pathways. The Center for Nuclear Waste Regulatory Analyses (CNWRA®) staff, who have developed and tested physical analog models of NDAA-type grout monoliths, have observed shrinkage between grout lifts and flow lobes[15] with both horizontally and vertically oriented, imperfectly bonded seams that form at their interfaces when placing relatively viscous formulations that tend to form lobes (Figure 3-5), enhancing preferential flow through the grout monolith.

Because temperature rise and gradients that form due to grout curing can lead to thermal cracking, NRC staff will monitor DOE's assessment and, as applicable, plans to reduce the potential for thermal cracking. NRC staff also will monitor other FTF design features to minimize adverse conditions such as alkali silica reaction (ASR) that results in dissolution of silica phases and cracking due to alkali silicate gel formation and expansion. The risk of ASR-based dissolution and cracking increases in the presence of cement or externally introduced alkalis, amorphous silica phases of certain concrete aggregates, and moisture. Although the final formulation used for Tanks 18 and 19 has relatively low cement content compared to other concretes used in construction applications, DOE's final formulation uses an aggregate potentially susceptible to ASR. Current standards calling for short-term testing (16 day tests) may not be sufficiently robust to evaluate the potential for long-term degradation associated with ASR. Finally, NRC staff will monitor FTF design features to minimize cracking of the tank grout due to differential settlement. Differential settlement may occur due to loading stresses imposed by the weight of the closure cap and may be enhanced by dissolution of calcareous zone materials at depth and subsequent collapse of overlying materials (see Chapter 6).

Because the DOE FTF PA made a number of assumptions regarding the chemical and hydraulic properties of the as-emplaced tank grout used to fill the HLW, NRC will monitor DOE's efforts to develop and test grout formulations that will meet PA requirements. Additionally, NRC staff will monitor DOE's efforts to deliver a high-quality grout from design placement in the field that performs as well as DOE assumed in its FTF PA.

After releases occur through the steel liners, the tank basemats are estimated by DOE's FTF PA to serve as an important barrier for many key radionuclides. In fact, in some cases, the tank basemats have savior characteristics in DOE's PA (i.e., basemats can compensate for

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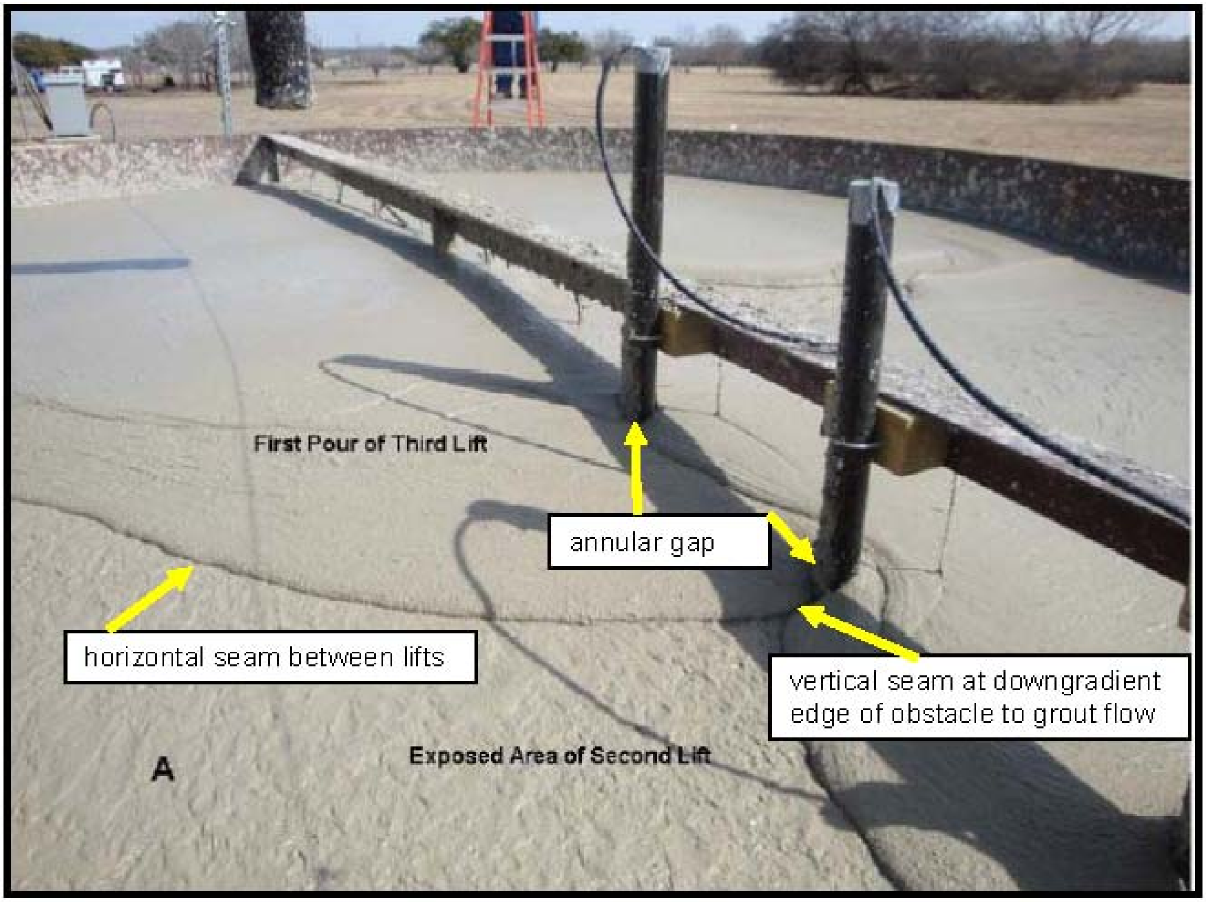
[15]A grout flow lobe is a fan-shaped mass of grout that forms on a slope by the changing direction of flow.



Panel A

Panel B

Figure 3-5. Tank Grout Features Important to Performance: Panel A is a Close-In View of Grout Seams and Gaps (Dinwiddie, et. al., 2012, Figure 3-8) and Panel B is an Example of Grout Lobes From F-Tank Farm Tank 18 Grouting (Photo Taken During June 12, 2012 Onsite Observation)

other failures or act in isolation to mitigate releases from the tanks when all other engineered barriers have failed). For instance, the basemats may serve as the most effective barrier in the FTF PA after long periods of time when the closure cap, steel liner, and tank grout have all failed as hydraulic barriers and key radionuclide solubility limits are a their highest levels (Oxidized Region III). However, anecdotal and other evidence exists that preferential flow pathways may be present in the tank basemats and that these pathways may have a significant impact on contaminant flow and transport.

For example, in 1960, waste leaked from HTF Tank 16 is thought to have breached the concrete vault and entered the surrounding soil (Davis, 1977). Tank documentation suggests that groundwater has historically intruded into FTF tank vaults following water table rise (McNatt, 1982). Therefore, NRC staff are concerned that assumptions regarding the ability of the concrete vaults to reduce radionuclide releases from the FTF tanks are overly optimistic. For these reasons, NRC staff will monitor assumed basemat performance for key radionuclides such as Pu and Np at FTF.

NRC Monitoring Under MA 3 "Cementitious Material Performance"

As listed in Appendix A and documented in more detail in NRC's TER (NRC, 2011),[16] NRC staff will consider the following MFs related to cementitious material performance that are considered important to meeting the 10 CFR 61.41 PO:

- Concrete Vault Performance (As it Relates to Steel Liner Corrosion),
- Grout Conditioning,
- Shrinkage and Cracking,
- Grout Performance,
- Basemat Performance, and
- Waste Stabilization (As It Pertains to ALARA).

More detailed discussion regarding NRC's concerns related to some of the aforementioned MFs is available in Appendix D.

3.3.1 Monitoring Factor 3.1: Concrete Vault Performance (As It Relates to Steel Liner Corrosion)

DOE assumes the grouted[17] concrete vaults that house the HLW tanks at FTF act as hydraulic barriers to fluid flow and provide a relatively passive environment for the steel liners or tanks, significantly limiting tank corrosion following closure. In some cases (for Types I and III tanks), DOE assumes steel liners are a barrier to fluid flow and prevent significant releases from the tanks during the entire performance period. Therefore, NRC staff will review reports, analog studies, and other information used to support DOE's assumption regarding initial conditions and performance of the concrete vaults. For example, NRC staff will review annual tank inspection reports that provide information regarding trenching, scarifying, and cracking of the concrete vaults, as well as information about groundwater intrusion into the tank vaults. NRC staff will review reports related to previous events that led to potential releases or groundwater

[16]Monitoring factors related to cementitious material performance are described in NRC staff's TER (NRC, 2011) except for monitoring factor 3.3 related to FTF tank grout design measures to minimize shrinkage and cracking. Mitigation of cracking is important to minimizing the occurrence of preferential flow pathways through the tank system, which is, however, discussed in detail in NRC staff's TER.

[17]Type IV tanks have no annulus and are, therefore, not grouted at the time of closure.

in-leakage through joints or cracks in the concrete vaults. Analog studies could include review and evaluation of information obtained from West Valley or other analog sites to better understand the potential for and rates of corrosion of HLW tanks/components, as well as mitigative design measures. As part of this MF, NRC staff also will consider the potential for earlier steel liner failure than assumed in DOE's PA due to corrosion of steel components (e.g., rebar) in the concrete vaults that are close to the vault surface.

If DOE performs additional modeling or experiments to study the potential for transport of deleterious species into the tank vaults and subsequent corrosion of steel liners or tanks, NRC staff will review the documentation or provide input on the design and results of the experiments. Experiments to study steel liner corrosion are expected to be relatively difficult to implement with unknown benefit compared to other experimental investigations recommended in NRC's TER and discussed in this monitoring plan. Therefore, NRC staff does not consider these experiments to be a high priority at this time. NRC staff will assume steel liners will not be effective at mitigating releases for the long time periods DOE relies on the steel liners for performance in the FTF PA and will investigate the support for the performance of other barriers to ensure POs can be met until such support for steel liner performance is provided. Should results of other investigations indicate FTF barriers that DOE relies on in its reference (or best-estimate) PA case are not expected to perform as well as assumed, NRC will give more thought to methods by which DOE could obtain additional support for steel liner performance assumptions.

3.3.2 Monitoring Factor 3.2: Groundwater Conditioning

As stated above, DOE assumes that infiltrating groundwater is able to flow through every pore space of the grout monolith, rather than coming into contact with a relatively small volume of potentially armored[18] tank grout along crack or fracture faces. Reactions between the infiltrating groundwater and tank grout cause the pH to increase from approximately 5 to 12 and the Eh to decrease from as high as +500 mV to as low as -600 mV. Tank groundwater conditioning to high pH and low Eh is important to maintaining low solubility, concentrations, and dose, because the chemistry of the groundwater dictates the solubility limits assigned to key radionuclides in the contaminated zone in DOE's reference PA case. If the infiltrating groundwater that has a drastically different chemistry than DOE assumed in the PA is able to contact the radioactivity in the contaminated zone, then concentrations leached from the tanks could be significantly higher than predicted much earlier in time.

Because groundwater table rise and preferential flow through the tank grout may lead to higher solubilities and releases from the tanks, NRC staff will monitor DOE experiments to study the potential for groundwater flow through cracks that may form in the tank grout (the potential for cracking is addressed in MF 3.3). If DOE cannot rule out bypass flow through the tank grout under MF 3.3 or water table rise above the bottom of FTF tanks under this MF, then it will be important for DOE to demonstrate the extent to which groundwater is conditioned when flow is primarily through preferential pathways through the tank grout. Although DOE assumes little to no conditioning in Configuration[19] G, a tank grout bypass scenario evaluated in response to

[18]Armoring may occur through precipitation of calcium carbonate on fracture and crack faces through a concrete degradation process referred to as carbonation. Armoring may preclude interaction of infiltrating groundwater with tank grout components interior to fracture faces that serve to condition the groundwater and maintain low solubilities or concentrations of key radionuclides.
[19]The term "configuration" is used in DOE's PA to describe various scenarios that are generally run to evaluate differences in waste release model and parameter assumptions.

NRC RAIs,[20] the dose prediction in Configuration G exceeded the 10 CFR 61.41 PO within the 10,000 year compliance period. Although DOE assumes the likelihood of Configuration G is low, NRC staff thinks the likelihood of this scenario may be underestimated. Therefore, more credit for groundwater conditioning may be needed in this alternative flow scenario to demonstrate compliance with the PO.

NRC staff will monitor DOE experiments or perform its own independent experiments to better understand the nature of flow through the tank grout as it impacts the extent to which infiltrating groundwater interacts with and is conditioned by the tank grout (this factor is closely related to MF 2.2[21]). If NRC staff concludes that bypass flow through preferential pathways in the tank grout is significant, DOE should implement an alternative conceptual model consistent with preferential flow through the tank grout to compute chemical transition times.

NRC staff also will review information regarding water table rise to evaluate the likelihood of this alternative conceptual model for waste release. Based on the results of the water table rise investigation, an alternative conceptual model may be proposed for a subset of FTF tanks to assess the impact on the compliance demonstration. Specifically, NRC staff will review historical water table elevation data for FTF wells to assess the likelihood of water table rise above the bottom of FTF tanks. NRC staff also will review design and construction of any DOE mitigation measures used to ensure that the water table remains below the bottom of FTF tanks. The water table is most likely to rise above Type IV tank bottoms, followed by Type I tank bottoms because of the lower elevations at which these tanks were constructed (Amidon, et al., 2012).

In the case where flow is primarily through preferential pathways, such as shrinkage gaps and cracks, DOE should design experiments to provide information on the expected level of groundwater conditioning for this type of flow. DOE has designed and constructed a lysimeter field experiment at the Savannah River Site (SRS) to study the mobility of various radionuclides in a saltstone waste form. This experiment could be leveraged to study the potential for groundwater conditioning for what is expected to be a relatively impermeable cementitious waste form. If infiltrating groundwater is not conditioned, DOE could design and construct column experiments with cracked FTF grout to study the extent to which groundwater may be conditioned by the tank grout under what is currently considered a more realistic scenario by NRC staff.

NRC will review documentation provided by DOE to support assumptions regarding the extent of groundwater conditioning for as-emplaced FTF tank grout. NRC staff may conduct the technical review activities in conjunction with an onsite observation to observe any laboratory or field experiments in this area. If results of waste release experiments conducted under MF 2.1 show key radionuclides in waste residuals have sufficiently low solubility when in contact with unconditioned SRS groundwaters, MF 3.2 related to the extent of conditioning (and 2.2 related to the longevity of conditioning) will no longer be needed by DOE to support the compliance

[20]Configuration G is evaluated in DOE RAI responses (SRR-CWDA-2009-00054, Rev. 1) and discussed in more detail in NRC staff's TER (NRC, 2011).

[21]The difference between MF 2.2 and MF 3.2 is that MF 2.2 focuses on the actual geochemical reactions that are occurring between groundwater and tank grout components that determine how the chemistry of the groundwater changes over time, whereas MF 3.2 assesses how groundwater flows through the tank grout. In other words, MF 2.2 is focused on the chemical aspects of how groundwater and tank grout components interact, while MF 3.2 is focused on the extent to which the nature (fracture or matrix) and rates of flow through the grout impact the ability of the groundwater to interact with the tank grout. Because MF 3.2 may influence the extent of reaction; it also may influence chemical transition times and is therefore closely related to MF 2.2.

demonstration and can be closed. If MF 2.1 results indicate unconditioned flow may lead to unacceptably high doses, then this MF will need to be evaluated by NRC and can be closed after DOE (i) shows matrix flow through the grout will dominate waste release or (ii) provides information to support assumptions regarding the level of groundwater conditioning for degraded (cracked) grout.

3.3.3 Monitoring Factor 3.3: Shrinkage and Cracking

As discussed, there are many mechanisms that could lead to cracking or creation of void space in the tank grout, which increases the likelihood of early, risk-significant releases and doses from the FTF tanks including the following:

- Steel Component Corrosion,
- Shrinkage Gap Development and Poor Grout-Bond Quality,
- Thermal Cracking,
- ASR, and
- Differential Settlement and Related Cracking.

DOE should consider design measures to minimize the occurrence of negative features, events, or processes that may promote shrinkage or cracking. For example, DOE should consider removal of in-tank equipment that could lead to development of shrinkage-induced annuli around equipment or corrosion of steel components and associated cracking due to corrosion product expansion. DOE also should promote the ability of the tank grout to fill all void spaces (e.g., grout should be self-leveling) to minimize imperfectly bonded grout seams and voids that may form in between grout pours. DOE should research and evaluate shrinkage compensating agents for use in its grout formulations to minimize shrinkage, shrinkage gap formation, and creation of annuli and void space within the tank grout. DOE should ensure temperature gradients are sufficiently low to prevent excessive thermal cracking. Calculations could be conducted to evaluate potential thermal gradients and/or instrumentation could be used to evaluate as-emplaced thermal evolution of the tank grout. Finally, DOE should ensure the tank grout is designed to consider the potential for cracking due to differential settlement (see Chapter 6 on site-stability for more detailed discussion). It also may be useful for DOE to research and deploy methods of detecting early crack development within tanks (e.g., through use of devices such as acoustic sensors).

NRC staff will review grout formulations, calculations, research, test methods, and results to ensure the disposal facility is designed to minimize fast flow path development. NRC staff may conduct technical reviews in conjunction with onsite observations that could include such activities as video inspections of grout pours, observations of grout tests, and inspection of test specimens.

It is important to note the intended low matrix hydraulic conductivity of the grout monolith may accentuate fast crack or bypass flow through the system because the grout matrix is expected to be quite impermeable to water flow, particularly for Type IV tanks that do not have cooling coils and are assumed, therefore, to degrade more slowly than grout in tanks containing internal fixtures. If it becomes clear that (i) it will be difficult to prevent preferential pathways from forming in the system, (ii) these preferential pathways may conduct a significant amount of unconditioned water, and (iii) unconditioned releases may exceed the dose standard, then it might be useful for DOE to explore methods under MF 3.2 to enhance contact of infiltrating water with the tank grout if such contact is shown to condition infiltrating groundwater and limit releases from the tanks to non-risk-significant levels.

MF 3.3 can be closed when DOE demonstrates (i) preferential fast flow into the waste zone will not occur or (ii) preferential fast flow into the waste zone will not adversely impact performance (e.g., the PO can be met under all chemical conditions as discussed in more detail under MA 2 "Waste Release").

3.3.4 Monitoring Factor 3.4: Grout Performance

After issuance of NRC's TER (NRC, 2011), DOE generated a number of documents developing and testing a final grout formulation for closure use in Tanks 18 and 19. NRC will perform technical review activities related to DOE's testing and development of grout formulations to meet design specifications. Additionally, NRC will monitor DOE's efforts to deliver a grout mix of sufficient quality to meet performance assumptions in DOE's FTF PA from design to as-emplaced conditions in the field. NRC staff will review relevant procedures and documentation related to such items as grout material procurement, production, testing, acceptance and placement in FTF components. NRC staff will perform technical review activities in conjunction with onsite observations. Onsite observations will include such activities as observations of grout material storage, tests, and acceptance of grout materials, live video streams of grouting operations, review of archived video footage, review of batch tickets for accepted and rejected loads, tour of the command center, and observation of mock-up tests or visual examination of test specimens. NRC staff can close this MF after it completes (i) review of DOE-generated grouting documentation and (ii) monitoring of grouting operations. If NRC identifies any issues, DOE also must adequately address the issues or provide plans to address the issues under another MF.

3.3.5 Monitoring Factor 3.5: Basemat Performance

The basemat is the last engineered defense against releases from FTF tanks. For some key radionuclides such as Np and Pu, it is the most effective barrier, limiting peak releases and doses in DOE's reference PA case. Because the basemats are, in most cases, more than 50 years old and have supported the weight of the waste-filled HLW tanks for many years, it is expected the basemats are chemically degraded and cracked. Additionally, tank vaults may contain features conducive to by-pass flow (e.g., leak detection channels or construction joints). Because attenuation of Np and Pu in the basemat is very important to the compliance demonstration and may be less than assumed in DOE's PA in the case of (i) flow through cracks or other preferential pathways, or (ii) if sorption potential for these two constituents is overestimated, NRC staff will monitor DOE efforts to study basemat sorption for these two constituents. DOE should address technical issues that experiments used to support basemat distribution coefficients (K_ds) for Pu and Np were flawed in that they represented solubility rather than sorption. DOE also should address the potential for degradation of the attenuating properties of the basemats over time (i.e., old, cracked concrete materials may be less sorptive than newer, uncracked concrete materials). NRC staff will review documentation and any analog studies that may provide additional information regarding the ability of the concrete basemats to attenuate release from FTF tanks, including information regarding groundwater inleakage for FTF tanks and release from HTF Tank 16.

This MF can be closed when sufficient information is available to support assumptions regarding attenuation of Np and Pu in the basemats, or when DOE provides sufficient information to show that Np and Pu doses will be below the dose limits prescribed in the POs with little to no performance from the concrete basemats (e.g., solubility limits for unconditioned groundwater are sufficiently low or natural attenuation of Pu is sufficiently high to compensate for underperformance of the basemat).

3.3.6 Monitoring Factor 3.6: Use of Stabilizing Grout (As It Pertains to ALARA)

DOE considers tank and vault grouting consistent with ALARA criteria. In its final WD (DOE/SRS–WD–2012–001), DOE explains that residual material remaining in the waste tanks after key radionuclides have been removed to the maximum extent practical will be stabilized with reducing grout, a chemically reducing environment known to minimize the mobility of the contaminants after closure. DOE indicates that waste tank grout fill is designed to have a low matrix permeability to enhance its ability to limit the migration of contaminants after closure. DOE also indicates that waste tank concrete vaults serve to significantly retard water flow through the waste tanks. In addition, DOE will fill the waste tank liners and annular space between liner and vault, if applicable, with cementitious material to further limit the amount of water infiltration into the waste tanks.

Consistent with WIR guidance in NUREG–1854 (NRC, 2007), NRC staff will review use of stabilizing materials to determine if DOE has made a reasonable effort to optimize mixing or encapsulating the waste with the stabilizing material. DOE should evaluate options to move or stabilize the waste present along the edge of the tanks that may present a relatively higher risk, including options to minimize shrinkage along the tank wall, if deemed ALARA. NRC staff will evaluate DOE's use of stabilizing materials to grout features of the tank and vault system that might otherwise lead to preferential flow through the engineered system and into the environment (e.g., grouting of leak detection channels and sumps contained within the concrete basemats).

NRC staff will conduct technical reviews and onsite observations under MFs 3.1 to 3.5, bearing in mind the additional function of the stabilizing grout to maintain doses ALARA. NRC staff can close MF 3.6 when MFs 3.1 through 3.5 are closed, and if NRC staff finds DOE's use of stabilizing cementitious materials consistent with ALARA criteria.

Closure of the Group of Monitoring Factors Related to MA 3 "Cementitious Material Performance"

MF 3.1 is contingent on the results of other studies. MFs 3.2 and 3.3 can be closed after DOE demonstrates that preferential pathways will not occur or will not significantly alter the compliance demonstration. MF 3.4 can be closed following grouting of the FTF tanks. MF 3.5 can be closed when DOE demonstrates that concrete basemats can effectively immobilize key radionuclides Np and Pu that are released from the tanks or that solubility control is effective at reducing Pu releases to non-risk-significant levels or that natural system attenuation is sufficient to compensate for underperformance of the concrete basemats. MF 3.6 will be closed when MFs 3.1 through 3.5 are closed, if NRC staff finds stabilization operations consistent with ALARA criteria.

3.4 MA 4 "Natural System Performance"

Importance of MA 4 "Natural System Performance"

The hydrogeological system at FTF performs as a significant natural barrier, helping to attenuate key radionuclide releases from FTF tanks to groundwater through such processes as dilution, dispersion, sorption,[22] and decay.[23] Natural attenuation can serve to (i) delay the timing of the peak dose and (ii) reduce concentrations and dose at the POC. Therefore, NRC staff will monitor natural system performance to assess compliance with the 10 CFR 61.41 PO.

NRC staff made two primary recommendations related to natural system performance in its TER (NRC, 2011)**:** (i) DOE should obtain support for averaging K_ds of multiple oxidation states to simulate the transport of Pu in the natural environment and (ii) DOE should provide additional data from tracer tests and calcareous zone outcrop locations to allow NRC and DOE to evaluate the significance of calcareous zone dissolution on flow and transport from the FTF. As shown in Figures 3-3 and 3-4 and Table 3-1, DOE assumes a significant amount of performance is achieved for sorption of Pu in the natural system (i) an approximately 10,000-year delay in the timing of the peak dose due to travel times in the vadose and saturated zones (Figure 3-4) and (ii) a reduction in the peak dose from Pu due to sorption in the natural system by approximately a factor of 10 (Table 3-1). The risk significance of the Pu K_ds is evident. Regarding characterization of the calcareous "soft zones" that are located in the lower portion of the Upper Three Runs Aquifer (UTRA), NRC staff is concerned these zones could act as conduits for fast groundwater flow, decreasing travel times and potentially minimizing dilution and natural attenuation in the aquifer. Site-specific sorption coefficients for the calcareous zones have not been developed and it is not clear the extent to which key radionuclide mobility will be affected by the presence of these zones. Faster travel times could lead to less decay, higher concentrations and earlier peak doses; less dilution and natural attenuation also could lead to higher predicted concentrations and doses at the POC.

NRC Monitoring Under MA 4 "Natural System Performance"

As listed in Appendix A and documented in more detail in its TER (NRC, 2011),[24] NRC staff will consider the following MFs related to natural system performance that it considers important to meeting the 10 CFR 61.41 PO:

- Natural Attenuation of Pu,
- Characterization of Calcareous Zones, and
- Environmental Monitoring.

3.4.1 Monitoring Factor 4.1: Natural Attenuation of Plutonium

Depending on the K_ds of Pu assumed in the natural environment, travel times from Tank 18 to the 1 m or 100 m points of compliance used in the intruder and member of the public dose

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[22]Sorption is used in a broad sense to describe the association of a groundwater contaminant with subsurface materials that can (i) lead to longer travel times or (ii) decreased concentration at the point of compliance.
[23]Decay can be significant when travel times to a well are expected to be similar to the half-life of key radionuclides [e.g., for key radionuclides such as Pu-239, Sr-90, and Cs-137 in DOE's reference (or best-estimate) PA case].
[24]This is true except for monitoring factor 4.3 related to environmental monitoring. NRC staff will review data collection and associated documentation to ensure the disposal facility is performing as intended.

assessments, respectively, could range from hundreds to tens of thousands of years. NRC staff concludes that DOE has not addressed issues associated with its K_ds averaging approach,[25] with site-specific studies indicating a range of K_ds anywhere from a few (three) L/kg to thousands (1,000s) L/kg for different oxidation states of Pu, with higher oxidation states of Pu tending to be more mobile. Furthermore, DOE has not provided sufficient information regarding the expected chemical form of Pu released from the tanks (see discussion under MA 2) and potential sorption of Pu released from the tanks in the sediments below. If arguments based on travel times are relied on to demonstrate compliance with the POs, then DOE should demonstrate that more mobile forms of Pu that can be transported to the 1 or 100 m points of compliance in hundreds of years cannot exist in risk-significant quantities in the subsurface at SRS. If arguments based on magnitude of peak dose are relied on to demonstrate compliance with the POs, then DOE should show that a combination of barriers that may include sorption of Pu to natural sediments leads to a dose below the dose-based standards.

NRC staff will perform technical reviews of DOE research and documentation related to Pu sorption in the subsurface of SRS including a recently prepared document re-evaluating vadose zone Pu K_ds prepared between issuance of NRC's TER and DOE's final WD (Almond, et al., 2012). NRC staff will review results of analog studies, such as the lysimeter studies related to Pu release from a saltstone waste form. Although the lysimeter studies consider releases from saltstone grouts, the lysimeter studies may provide useful information regarding the potential mobility of Pu in the natural soils located above and below the saltstone waste form. However, DOE should consider performing experiments that are more relevant to FTF that take into account the chemical forms of Pu expected to be leached from the tanks, as well as the impact of grout leachate on Pu K_ds.

Technical review activities may be conducted in conjunction with onsite observations of any experiments developed to study the attenuation of Pu in SRS soils. This MF can be closed when DOE provides support for its treatment of Pu sorption in the subsurface at FTF or DOE shows that Pu sorption in the subsurface is not needed to support its compliance demonstration (e.g., solubility control effectively limits Pu releases into the natural environment to non-risk-significant levels).

3.4.2 Monitoring Factor 4.2: Calcareous Zone Characterization

Another source of uncertainty in DOE's far-field model is the treatment of the calcareous "soft zones," located in the lower portion of the UTRA. The focus of studies related to calcareous zones has been facility or site stability. NRC staff observed that DOE studies appear to give less attention to the hydrogeologic properties of these zones that may impact contaminant flow and transport from the FTF. DOE argues that monitoring data have not revealed any noticeable impacts on hydraulic heads or contaminant transport to date, but no tracer testing has been performed to improve understanding of transport within the pseudo-karst-like soft zones, nor has downhole imaging of water velocities been performed at known soft zone locations.

DOE could monitor flow velocities at screen levels both consistent and inconsistent with known existing soft zones to assess local fast flow path gradients of soft zones to provide additional confidence that current PA groundwater modeling treatment is acceptable. To date, mapping of surface water seeps from the UTRA-Lower Zone rocks along Upper Three Runs Creek and Four Mile Branch has not focused on surface seeps or other features associated with these

[25] In lieu of modeling different oxidation states of Pu that may be present in the natural system, DOE averages the K_ds of multiple oxidation states together in assigning a K_ds for a single Pu species.

zones, but DOE has suggested they are willing to perform both tracer testing and outcrop mapping of seeps.

NRC staff should observe field tests and review and evaluate results of tracer tests and field mapping DOE may conduct to ascertain the significance of existing calcareous "soft" zones on flow and transport from the FTF. Staff will review relevant geotechnical logs acquired in the vicinity of FTF to stay informed of the potential for and characteristics of soft zones that may be identified in the future. Finally, if DOE opts to employ downhole visualization or other methods to monitor local groundwater velocities associated with soft zones, NRC staff will review and evaluate DOE's analysis of these data. NRC may conduct technical review activities in conjunction with onsite observations of field activities, such as calcareous zone outcrop mapping on Upper Three Runs Creek. This MF can be closed when DOE has provided NRC sufficient information to show its treatment of calcareous zones in the FTF PA is reasonable or adequate to assess risk. If NRC concludes that DOE's treatment of calcareous zones in the FTF PA is not reasonable or appropriate, DOE should evaluate the risk-significance of a more adequate representation.

3.4.3 Monitoring Factor 4.3: Environmental Monitoring

NRC staff will review any data collected by DOE for the FTF facility for the purpose of evaluating FTF disposal facility performance. While early releases from the disposal facility are not expected, groundwater monitoring can serve as a valuable tool for early detection of potential issues with the disposal facility design to allow sufficient time to institute mitigative measures. Additionally, groundwater monitoring data can provide useful validation data from which to assess the adequacy of DOE PA models in evaluating risk from the FTF disposal facility. For these reasons, NRC staff will review and evaluate groundwater monitoring data as a technical review activity under this MF.

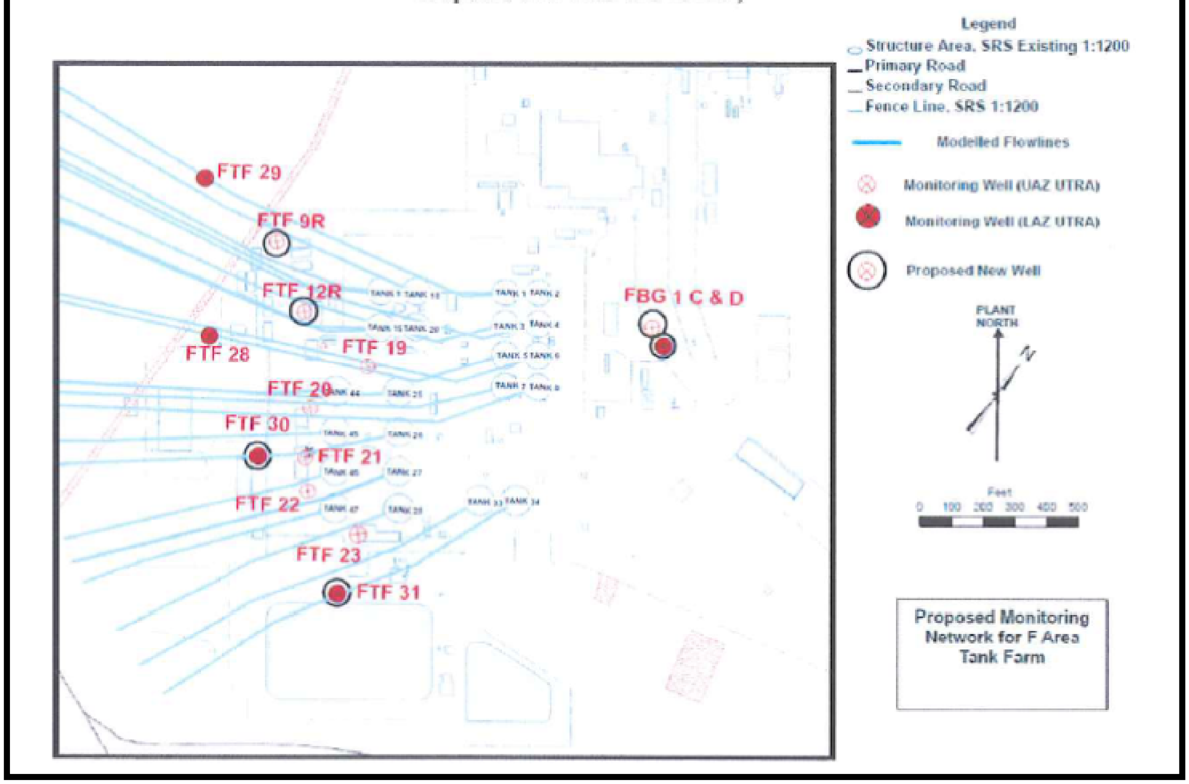
DOE monitors FTF groundwater, as described in the FTF Groundwater Monitoring Plan (SRNS–RP–2011–00995). DOE currently monitors eleven wells at FTF. Nine of the 11 wells are older wells (constructed between 1972 and 1984), screened in the upper zone of UTRA: FTF-15 to -23. Two newer wells, FTF-28 and -29, constructed in 2002, are located a little further down gradient and are screened in the lower zone of UTRA. Field parameters and constituents monitored include pH, conductivity, temperature, turbidity, depth to water, gross alpha, non-volatile beta, tritium, nitrate/nitrite, chromium, and Tc-99.[26] Tc-99 has been detected in well FTF-28 at significant concentrations (e.g., 900–1,000 pCi/L) that has been attributable to a documented release from Tank 8 that occurred in 1961.[27]

DOE (SRNS–RP–2011–00995) notes the monitoring network could be improved by (i) increasing coverage on the northwest corner of the FTF, (ii) increasing well coverage in the

[26]Tc-99 is only monitored at wells FTF-28 and -29.

[27]It is significant to note that FTF-28 is not located along the center-line of flow paths from Tank 8. This means that either (i) concentrations could be substantially higher along the center-line with the concentrations at FTF-28 being a result of lateral dispersion or (ii) Tank 8 is not the only possible source of the FTF-28 groundwater plume. It is also significant to note that Tc-99 is very mobile in the environment and would not be expected to be present in the aquifer 50 years after its release into the vadose zone at FTF unless it were held up in an engineered system. An alternative hypothesis is that leaks from the sewer lines resulted in UTRA contamination at wells FTF-28 and FSL-11C (FSL-11C is part of the larger general separations area monitoring well network). However, well FTF-28 is screened in the lower zone of the UTRA. Because the well is also located in close proximity to the sewer lines, it is not clear that contamination could be vertically transported to the lower zone of the UTRA over such a small lateral distance. Therefore, NRC may perfrom backwards particle tracking from FTF-28 to identify potential source areas during monitoring.

lower aquifer zone, and (iii) installing upgradient wells to establish background conditions. SRS plans to install six new wells to implement these improvements, including two background wells, and four downgradient wells located in both the upper zone (two wells) and the lower zone (two wells) of the UTRA. The locations of the new wells are circled in Figure 3-6. Sampling of wells FTF 15–18 will be discontinued. Additional analyses under the proposed monitoring plan include: cadmium, manganese, sodium, and, if above gross alpha or non-volatile beta trigger levels alpha, beta, or gamma speciation may be conducted by DOE.[28] NRC staff will evaluate the FTF monitoring well network and associated data collection as a technical review activity under this MF.



(Blue lines represent approximate groundwater flow paths based on FTF groundwater modeling. Proposed new wells are circled)

Figure 3-6. Proposed F-Tank Farm Groundwater Monitoring Locations (SRNS-RP–2011–00995)

Closure of the Group of Monitoring Factors Under MA 4 "Natural System Performance"

NRC may conduct technical review activities for this monitoring activity in conjunction with onsite observations related to groundwater sampling, well construction, and other field activities. South Carolina Department of Health and Environmental Control oversight may be leveraged in this area to ensure the quality of data collected. This MF will remain open and will not be closed. However, once MF 4.1 and 4.2 have been closed, the MA will be changed to environmental monitoring. MA 4 will be renamed "Environmental Monitoring" once MF 4.1 and 4.2 have been closed. MA 4 will remain open indefinitely.

[28]DOE (SRNS–RP–2011–00995, p. 22) lists I-129 as a constituent to be monitored at FTF; however, Table 3 in the same report does not appear to list I-129 in the analyte column.

3.5 MA 5 "Closure Cap Performance"

Importance of MA 5 "Closure Cap Performance"

Although DOE's sensitivity and uncertainty analyses indicate the closure cap has minimal impact on peak dose and in most cases serves as a redundant barrier,[29] NRC staff concluded that in certain cases, the FTF closure cap could be important to mitigating risk from the disposal facility and in maintaining doses ALARA. In fact, DOE's barrier analysis shows that if other barriers do not perform as well as expected, the closure cap could become a more important barrier limiting release from the disposal facility. Over long periods of time, DOE also assumes that the closure cap limits infiltration rates to 30.5 cm/yr [12 in/yr], below the background infiltration rate of 38 cm/yr [15 in/yr]. Longer-term lowering of the infiltration rate helps to (i) decrease releases of key radionuclides from the disposal facility and (ii) prolong transition times to higher solubility of many key radionuclides. Based on the potential importance of the closure cap in meeting the POs in 10 CFR Part 61 and the limited support that has been provided by DOE for this barrier in its FTF PA, NRC staff will monitor closure cap performance.

NRC Monitoring Under MA 5 "Closure Cap Performance"

As listed in Appendix A and documented in more detail in its TER (NRC, 2011), NRC staff will consider the following MFs related to waste release that are considered important to meeting the 10 CFR 61.41 PO:

- Long-Term Hydraulic Performance of the Closure Cap,
- Long-Term Erosion Protection Design, and
- Closure Cap Functions as They Pertain to ALARA.

3.5.1 Monitoring Factor 5.1: Long-Term Hydraulic Performance of the Closure Cap

In its TER (NRC, 2011), NRC staff discussed (i) the uncertainty in the processes being modeled for the FTF closure cap and (ii) the limited support for several of the closure cap assumptions. DOE should provide additional support for the long-term hydraulic conductivity of the foundation layer, which acts to reduce the long-term infiltration to the disposal facility. DOE assumed the foundation layer would limit the infiltration rate to 30.5 cm/yr [12 in/yr], slightly less than the estimated background infiltration rate of 38 cm/yr [15 in/yr]. NRC will monitor additional information to support the assumed long-term hydraulic conductivity of the foundation layer.

In addition, NRC staff will monitor construction quality and settlement at the FTF to help ensure assumed performance of the High Density Polyethylene/Geosynthetic Clay Liner (HDPE/GCL) composite layer is not adversely impacted. Although the HDPE/GCL composite layer does not significantly contribute to the long-term hydraulic performance of the closure cap, DOE assumes it is a significant barrier to infiltration for several hundred years after site closure. Because the performance of the HDPE/GCL layer is sensitive to construction quality and differential

[29]NRC staff concluded that DOE's reference (or best-estimate) PA case shows the FTF closure cap is a redundant hydraulic barrier because other, more robust hydraulic barriers, such as the steel liners and tank grout used to fill the cleaned tanks, are present and expected to outperform the closure cap for longer periods of time under most scenarios, including the reference case DOE used in its FTF PA. However, it is important to note the closure cap is the only barrier assumed to provide long-term infiltrating-reducing capabilities, albeit at modest levels. Figure 3-4 shows barriers to timing of tank farm releases in DOE's reference case.

settlement, NRC will monitor the quality assurance/quality control for closure cap construction and settlement data collected during FTF operations as well as nearby facilities. NRC also will review relevant studies and tests related to HDPE/GCL performance. This MF can be closed after DOE's construction of the closure cap and demonstration of its hydraulic performance.

3.5.2 Monitoring Factor 5.2: Long-Term Erosion Protection Design

As documented in its TER (NRC, 2011), NRC staff recommended that DOE provide additional support for the long-term erosion of the topsoil layer and conduct a preliminary evaluation of erosion protection designs. Long-term maintenance of the topsoil and vegetative closure cap is important to closure cap performance, because evapotranspiration dominates the modeled water balance distribution for SRS precipitation. DOE should evaluate potential loss of soil and development of gullies due to cumulative effects of soil loss from frequent rainfall events. Effects of high frequency and low intensity events can dominate long-term erosion processes. In addition, DOE did not evaluate the resistance of a degraded vegetation cover to gully erosion. A Bahia grass, bamboo, or pine forest vegetative cover could be degraded by fire or extended drought, thereby affecting the capability of the engineered cover to resist erosion. NRC staff will review and evaluate information pertaining to erosion processes of the vegetative and topsoil layers, including cover maintenance activities.

DOE should conduct a preliminary evaluation of erosion protection designs (e.g., evaluation of an acceptable rock source, the ability of an integrated drainage system to accommodate design features) to verify assumptions related to closure cap performance can be met. The design of perimeter drainage structures that convey runoff and infiltration from the cover and divert runoff from surrounding areas will affect resistance of these structures to erosion that could also affect the stability of the cover side slopes and the cover itself. If the vertical hydraulic conductivity of the native soil, on which the perimeter drainage channel is constructed, is not sufficiently high to allow ponded water to infiltrate vertically, it could flow toward the tanks. The final design for the cover and associated drainage structures should consider their performance and degradation during the long, post-institutional control period. If DOE performs simulations of the influence of clogging and ponding in the perimeter drainage structures on flow in the vadose zone, NRC will review results of these simulations to evaluate risk significance of the uncertainties in the long-term performance of the perimeter drainage structure. This MF can be closed after DOE's construction of the closure cap and demonstration of its physical stability.

3.5.3 Monitoring Factor 5.3: Closure Cap Functions That Maintain Doses ALARA

DOE lists the infiltration reducing function of the closure cap as part of its ALARA demonstration under 10 CFR 61.41. In addition to reducing short-term, as well as long-term infiltration rates, the closure cap serves many functions that are not specifically discussed in DOE's FTF PA. For example, the closure cap provides defense in depth to ensure relatively high specific activity radionuclides are present in significant quantities, such as Sr-90 and Cs-137, are not released from FTF tanks and ancillary equipment before they decay to negligible levels. During the period of a few hundred years after FTF closure, the closure cap may reasonably be assumed to be effective in minimizing infiltration through the disposal facility.

Although not specifically discussed in DOE's PA, another important function of the closure cap is that it may limit infiltration and transport of deleterious species into the engineered disposal system such as carbon dioxide, oxygen, chloride, sulfate, and slightly acidic groundwater that could accelerate material degradation of cement vaults, as well as accelerated corrosion of the HLW tanks. Therefore, construction of a well-designed closure cap also may benefit the longevity of other engineered barriers at the FTF.

Finally, the closure cap may have a minor but detectable impact on water table elevations local to FTF. Barriers constructed to reduce the likelihood of periodic water table rise above the bottom of the tanks may be needed to support the compliance demonstration and may be considered ALARA. The alternative waste release configuration where the water table rises and falls above and below the tank bottoms is especially important for Type IV tanks that are located at or in close proximity to the water table, based on historical water table data because the configuration could lead to accelerated corrosion and higher release rates of key radionuclides to the UTRA.

For these reasons and other closure cap functions listed in Chapter 4, related to the 10 CFR 61.42 PO, NRC staff will monitor DOE's disposal actions as they pertain to FTF closure cap design, construction, and maintenance consistent with ALARA criteria.

Closure of the Group of Monitoring Factors Under MA 5 "Closure Cap Performance"

This MA will remain open throughout DOE's development, construction, and completion of a final closure cap, unless final design information indicates the MFs are not risk-significant. When DOE develops a final closure cap design, NRC will revise the monitoring plan, as appropriate, to describe the monitoring activities relevant to the final design. NRC staff will monitor DOE's development of specific designs for the closure cap and determine if these designs are likely to significantly alter DOE and NRC conclusions regarding the conceptual design analyzed in the PA. Prior to any construction activities, NRC staff will review specifications for closure cap construction materials and quality assurance/quality control procedures for assuring these materials meet specifications. During construction, NRC staff should observe the placement of these materials and the quality control testing to assure the as-built closure cap will meet design specifications. NRC staff also will evaluate available data from similar covers built on the larger SRS site and other humid sites.

3.6 MA 6 "Performance Assessment Maintenance"

Importance of MA 6 "Performance Assessment Maintenance"

DOE Manual 435.1-1, Change 1, (DOE, 2001) requires DOE PAs to be maintained to evaluate changes that could affect the performance, design, and operation bases for the facility. DOE Manual 435.11-1 (DOE, 2001) requires the maintenance to include research, field studies, and monitoring necessary to address uncertainties or gaps in existing data. DOE prepares an annual PA maintenance program implementation plan that summarizes activities related to the following areas for the FTF: (i) annual maintenance program activities; (ii) PA development or revisions; and (iii) research and testing activities. The implementation plan for fiscal year 2012 is documented in SRR–CWDA–2012–00020.

NRC used risk insights to prioritize the recommendations identified in its TER (NRC, 2011) and anticipates that DOE, as part of its PA maintenance program, might use a graded approach to focus on development of support for key modeling assumptions, such as those identified under other MAs (e.g., MA 2) to enhance confidence in the PA. NRC will monitor DOE's PA maintenance activities related to key modeling assumptions under other MAs identified in this monitoring plan. The insights generated from focusing on key modeling assumptions would then inform the need for further data collection, experimental studies, and modeling to address MFs identified under this MA.

NRC Monitoring Under MA 6 "Performance Assessment Maintenance"

Under this MA, NRC will monitor DOE activities associated with the FTF PA maintenance program that are related to NRC recommendations to improve model support and parameter justification, including representation of uncertainty in models and parameters. Appendix A provides a cross-walk of specific NRC recommendations identified in its TER (NRC, 2011) that fall under this MA. Specifically, NRC will consider the following MFs related to DOE's PA maintenance activities for recommendations that NRC, based on the current understanding, identifies as lower significance to demonstrating compliance with the POs or may require a longer time horizon to complete based on current information:

- Scenario Analysis,
- Model and Parameter Support, and
- FTF PA Revisions.

3.6.1 Monitoring Factor 6.1: Scenario Analysis

During the monitoring period, NRC staff will review PA revisions to evaluate adequacy of scenarios considered. Specifically, NRC staff will review the DOE methodology for identification, screening, and dispositioning of features, events, and processes (FEPs) and the formation of scenarios considered in the PA. NRC staff should verify FEPs identified by DOE, including all FEPs having a potential to influence compliance with POs. NRC staff should examine the technical basis for screening FEPs from further consideration in the PA. NRC staff also should examine DOE bases for the formation of scenarios considered in the PA to determine whether they include all FEPs that have not been screened from further consideration.

Since NRC issued its TER (NRC, 2011), DOE has documented an evaluation of FEPs for the FTF PA. NRC staff will review and comment on the evaluation as a technical review activity. NRC will close this MF when DOE demonstrates that all risk-significant FEPs have been (or will be under another MF) adequately evaluated in PA documentation.

3.6.2 Monitoring Factor 6.2: Model and Parameter Support

As documented in NRC's TER (NRC, 2011), NRC staff provided a number of recommendations regarding the technical bases for model selection and justification of parameter ranges and distributions. NRC staff will review DOE's PA revisions to evaluate the selection of models and justification of parameters. Specifically, NRC staff will examine information DOE generates, including experimental and site characterization data and information from literature, to support model selection and justify parameters. NRC staff also will review DOE methods to characterize data and model uncertainty and propagate the uncertainty through the PA. NRC staff will use a graded approach to focus on aspects of most importance to demonstrating compliance with the POs. This MF can be closed when DOE provides sufficient information to support risk-significant models and/or model parameters listed in Appendix A related to MF 6.2.

3.6.3 Monitoring Factor 6.3: F-Tank Farm Performance Assessment Revisions

It is anticipated that DOE will update its current FTF PA (SRS–REG–2007–00002, Rev. 1) in the future, to incorporate new and significant information collected since preparation of its 2010 FTF PA. NRC staff will review the revised PA and issue a TER documenting the results of its review. NRC anticipates results of the review, as documented in NRC's TER, will be used by NRC to update this monitoring plan in the future. NRC staff will pay special attention to supporting documentation generated since the last PA revision, including results of experiments, analog studies, models, and peer reviews conducted to support the key MAs listed in this monitoring plan, as well as lower priority items listed under MA 6 "PA Maintenance."

Closure of the Group of Monitoring Factors Under MA 6-PA Maintenance

NRC staff expects the PA Maintenance MA will remain active until all recommendations have been resolved (or are deemed unnecessary to the compliance demonstration), and possibly for the entire duration over which DOE performs maintenance activities related to the FTF PA. Alternatively, NRC staff could close this group of MFs, if it determines DOE's PA maintenance program is sufficient to evaluate new and significant information related to FTF compliance with 10 CFR 61.41 in the futre.

4 MONITORING TO ASSESS COMPLIANCE WITH 10 CFR 61.42

Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed.

Protection of individuals from inadvertent intrusion considers the potential risks to individuals who are unknowingly exposed to radiation from disposed waste while engaging in normal activities while occupying the site. Generally, compliance with the waste classification system at 10 *Code of Federal Regulations* (CFR) 61.55 ensures protection of inadvertent intruders. However, for waste streams that were not considered in the development of 10 CFR Part 61 [NUREG–0945 (NRC, 1982)], such as the residual waste projected to remain in F-Tank Farm (FTF), it would be prudent to assess the performance of the disposal facility to limit radiological exposures to inadvertent intruders to demonstrate compliance with the performance objective (PO).

Exposures to radiation can be through direct contact with the waste or indirect exposure to the radiation from buried waste while onsite. Direct contact could occur as a result of an activity that disturbs the waste zone directly. Examples of activities that could lead to direct contact of radioactivity by an inadvertent intruder include excavation during dwelling construction and well drilling. The U.S. Department of Energy (DOE) rules out excavation for dwelling construction in its performance assessment (PA) because DOE assumes a minimum of 3-m [10-ft] clean cover is present and most residential dwellings disturb less than 3-m [10-ft] of soil. Although well drilling was considered a potential direct intrusion event in DOE's PA, well drilling into a high-level waste (HLW) tank was considered unlikely in DOE's PA, given the presence of multiple redundant barriers such as the closure cap, tank grout, and steel liner that would make drilling more difficult and based on regional experience would likely alert a driller accustomed to drilling into softer materials to the potential hazards of the disposal facility. Instead, DOE considered intrusion into transfer lines more likely. Nonetheless, because FTF waste is located several meters below grade underneath a closure cap, DOE also considers exposures resulting from indirect contact with contaminated onsite groundwater as a more likely exposure scenario for an inadvertent intruder. The basis for the 10 CFR 61.42 compliance demonstration is therefore calculations of potential dose to a well driller who intrudes into the FTF transfer lines and the potential dose to a groundwater receptor.

Because 10 CFR Part 61 relies on the waste classification system to ensure protection of inadvertent intruders, the regulation does not specify a time period for an assessment. Low-level waste and waste incidental to reprocessing guidance found in NUREG–1573 (NRC, 2000) and NUREG–1854 (NRC, 2007) suggest a 10,000 year period of performance is generally sufficient for demonstration of compliance with 10 CFR 61.41. Likewise, the U.S. Nuclear Regulatory Commission (NRC) considers this time period appropriate for assessment of compliance with 10 CFR 61.42. However, longer evaluation periods may be necessary to capture the peak dose and provide insights on facility (natural and engineered) performance for certain long-lived wastes.

To determine the dose to a potential receptor, DOE also must select a point of compliance (POC). NRC assumes in the development of 10 CFR Part 61 [NUREG–0945 (NRC, 1982)] the intruder excavated into a disposal cell or extracted water from a well located at the boundary of the disposal area after the end of the institutional control period. DOE assumes the inadvertent intruder installs a well located 1 m from the boundary of the disposal facility.

NRC staff considers this appropriate to assess potential inadvertent intruder exposures to contaminated groundwater.

NRC staff evaluated DOE's assessment of key FEPs associated with disposal facility performance that are estimated to have the largest impact on the 10 CFR 61.42 compliance demonstration based on the criteria discussed above. NRC staff found several monitoring areas (MAs) are important to meeting the 10 CFR 61.42 PO. Because the groundwater pathway is evaluated for both the 10 CFR 61.41 and 61.42 POs, with the only difference being the POC (100 m versus 1 m, respectively) and the allowable dose {0.25 mSv/yr [25 mrem/yr]} versus 5.0 mSv/yr [500 mrem/yr], each MA that is important for demonstrating compliance with 10 CFR 61.41 also is important for demonstrating compliance with 10 CFR 61.42. In general, NRC staff expects that compliance with the 10 CFR 61.41 PO will be bounding for the 10 CFR 61.42 evaluation. This is true because the factor difference between the dose standards (20 times higher for the 10 CFR 61.42 evaluation) is greater than the difference in concentrations between the 1 m and 100 m points of compliance for most key radionuclides (e.g., concentrations of key radionuclides are around 10 times greater at 1 m than they are at 100 m for relatively sorbing Pu-239).

However, because DOE relies on timing of the peak dose to demonstrate compliance with the POs in its reference (or best-estimate) PA case, the 10 CFR 61.42 compliance demonstration could be bounding for those radionuclides whose travel times are assumed to be prolonged between the 1 and 100 m points of compliance (e.g., Pu-239). Additionally, because 10 CFR 61.41 does not consider a direct intrusion case (e.g., intrusion into the transfer lines), constituents important to the 10 CFR 61.42 evaluation may not be important for the 10 CFR 61.41 evaluation and will be highlighted in MA 1 "Residual Inventory." In general, NRC staff considers MA and MA factors discussed in Chapter 3 with respect to 10 CFR 61.41 applicable to 10 CFR 61.42 discussed in Chapter 4 and will not be repeated. However, special considerations are discussed below for each MA.

4.1 MA 1 "Inventory"

Monitoring Factor 1.1: Final Inventory and Risk Estimates (Additional Considerations)

The FTF PA reports a peak 20,000-year dose for the chronic intruder of 0.75 mSv/yr [75 mrem/yr] due to groundwater dependent pathways with most of the dose from vegetable and water ingestion from Np-237.[30] Other important radionuclides from the groundwater pathway include Th-229 and U-233, although DOE indicated its plans to eliminate these two radionuclides from the list of highly radioactive radionuclides (HRRs) that is used to identify constituents in the waste residue to be sampled by DOE, following cleaning based on low inventories of these two radionuclides in cleaned Tanks 18 and 19. NRC staff will review special analyses prepared for each cleaned tank to ensure intruder risks reported in the FTF PA are appropriately assessed and evaluated under monitoring factor (MF) 1.1. This MF can be closed after NRC staff reviews each special analysis developed by DOE for FTF tanks and concludes that DOE has adequately evaluated the risk to the inadvertent intruder.

Monitoring Factor 1.2: Residual Waste Sampling (Additional Considerations)

DOE's conclusion that inventories of Th-229 and U-233, which may be important to the 10 CFR 61.42 analysis, were overestimated in the PA, is based on analyses of these

[30]The peak of the mean dose in the probabilistic analysis is 6.4 mSv/yr [640 mrem/yr].

radionuclides in cleaned Tanks 18 and 19. However, as stated in NRC's technical evaluation report (NRC, 2011), unless DOE can show that final inventories in other tanks are similar to final inventories in Tanks 18 and 19, DOE should continue to characterize samples for these radionuclides. NRC staff will review sampling and analysis plans to ensure all HRRs are sampled, or a basis for exclusion of an HRR is provided. This MF can be closed when NRC concludes that DOE has provided sufficient information to support its list of HRRs (or provides sufficient basis for removal of radionuclides from its list of HRRs) for each FTF tank.

Monitoring Factor 1.3: Residual Waste Volume

There are no special considerations under MF 1.3 for the 10 CFR 61.42 analysis.

Monitoring Factor 1.4: Ancillary Equipment Inventory

Short-lived radionuclides Sr-90/Y-90 and Cs-137/Ba-137 that may not be considered important by DOE or NRC to the 10 CFR 61.41 evaluation could be important for the 10 CFR 61.42 analysis, because the 10 CFR 61.42 analysis considers direct intrusion into the FTF transfer lines at 100 years, when these radionuclides may still be present in risk-significant quantities.[31] In fact, the peak dose within 10,000 years for the chronic intruder scenario is 0.73 mSv/yr [73 mrem/yr], with the most important pathway being the ingestion of vegetables contaminated with drill cuttings at the time of intrusion at 100 years, due to relatively short-lived radionuclides Sr-90/Y-90 (56 percent) and Cs-137/Ba-137 (44 percent). However, because the estimated does is significantly below the 5 mSv/yr [500 mrem/yr] dose standard, inventory of these radionuclides could potentially be higher, while still maintaining compliance with the dose standard. NRC staff should ensure risks associated with these relatively short-lived radionuclides are bounded by the PA or a special analysis is performed to assess the increased risk associated with a higher than assumed inventory, once final estimates of transfer line inventories are assessed through additional characterization. DOE indicated in response to NRC comment (SRR–CWDA–2009–00054, Rev. 0) its intent to verify PA assumptions regarding transfer line inventories and listed this activity under Section 8.2 "Further Work" in its FTF PA (SRS–REG–2007–00002, Rev. 1). NRC staff will monitor DOE's efforts in this area to ensure the assumed transfer line inventories are sufficiently bounding or that increased risk is assessed. This MF can be closed when NRC staff concludes that DOE has adequately assessed the risk associated with transfer lines.

Monitoring Factor 1.5: Waste Removal (As It Pertains to ALARA)

MF 1.5 related to as low as is reasonably achievable (ALARA) does not apply to the 10 CFR 61.42 evaluation.

4.2 MA 2 "Waste Release"

Monitoring Factor 2.1: Solubility Limiting Phases/Limits and Validation

There are no special considerations under MF 2.1 for the 10 CFR 61.42 analysis.

[31]The 10 CFR 61.41 analysis is dominated by groundwater dependent pathways and releases from FTF components are not assumed to occur for 100s to 1,000s of years, allowing sufficient time for decay of relatively short-lived radionuclides, such as Cs-137 and Sr-90.

Monitoring Factor 2.2: Chemical Transition Times and Validation

There are no special considerations under MF 2.2 for the 10 CFR 61.42 analysis.

4.3 MA 3 "Cementitious Material Performance"

Monitoring Factor 3.1: Concrete Vault Performance (Additional Considerations)

Because DOE relies on grouted tanks and vaults in the FTF PA to deter inadvertent intrusion into the HLW tanks[32], NRC staff will perform routine monitoring of DOE's reliance on cementitious materials to ensure FTF PA assumptions regarding the ability of the tank vaults to serve as a recognizable and durable barrier to intrusion are valid. This MF will be reviewed in conjunction with MF 3.4 and can be closed following closure of FTF tanks.

Monitoring Factor 3.2: Groundwater Conditioning

There are no special considerations under MF 3.2 for the 10 CFR 61.42 analysis.

Monitoring Factor 3.3: Shrinkage and Cracking

There are no special considerations under MF 3.3 for the 10 CFR 61.42 analysis.

Monitoring Factors 3.4: Grout Performance (Additional Considerations)

Because DOE relies on the grouted tanks and vaults in the FTF PA to deter inadvertent intrusion into the HLW tanks[33], grouting activities under MA 3 "Cementitious Materials Performance" will also be monitored under 10 CFR 61.42. NRC will perform routine monitoring of DOE's use of grout materials to stabilize HLW tanks to ensure FTF PA assumptions regarding the ability of the grouted tank and vaults to serve as a recognizable and durable barrier to intrusion remain valid. This MF will be reviewed in conjunction with MF 3.1 and can be closed following closure of FTF tanks.

Monitoring Factor 3.5: Basemat Performance

There are no special considerations under MF 3.5 for the 10 CFR 61.42 analysis.

Monitoring Factor 3.6: Use of Stabilizing Grout (As it Pertains to ALARA)

MF 3.6 related to ALARA does not apply to the 10 CFR 61.42 evaluation (there are no ALARA provisions in 10 CFR 61.42).

[32]DOE only considers intrusion into the HLW tanks in sensitivity analyses due to assumed robustness of the grouted tank and vault system.
[33]DOE only considers intrusion into the HLW tanks in sensitivity analyses due to assumed robustness of the grouted tank and vault system.

4.4 MA 4 "Natural System Performance"

Monitoring Factor 4.1: Pu Distribution Coefficients (K_ds) and Averaging (Additional Considerations)

Due to potential reliance on travel time of Pu to the 100 m POC for the 10 CFR 61.41 analysis, NRC will specifically consider whether the shorter distance and travel time to the 1 m POC for the 10 CFR 61.42 analysis makes compliance with the latter PO bounding. As discussed in Section 3.4.1, NRC staff has concerns with the K_d averaging approach used by DOE that tends to delay travel times to the 10 CFR 61.41 and 61.42 POCs. NRC staff will review information generated by DOE and perform independent modeling to assess whether more mobile forms of Pu, if evaluated explicitly in DOE's PA modeling, could reach the inadvertent intruder POC within 10,000 years. This MF can be closed when NRC staff concludes that DOE has adequately assessed the timing and magnitude of Pu-239 release and transport to the 1 m POC.

Monitoring Factor 4.2: Calcareous Zone Characterization

NRC staff does not think calcareous zone characterization is as important to the 10 CFR 61.42 analysis because contaminant plumes emanating from the FTF are less likely to traverse the lower zone of the UTRA where the calcareous zone is present during their travel to the (1 m) POC, where the inadvertent intruder dose is assessed. Therefore, there are no special considerations under MF 4.2 for the 10 CFR 61.42 analysis.

Monitoring Factor 4.3: Environmental Monitoring

There are no special considerations under MF 4.3 for the 10 CFR 61.42 analysis.

4.5 MA 5 "Closure Cap Performance"

Monitoring Factor 5.1: Long-Term Erosion Protection Design

There are no special considerations under MF 5.1 for the 10 CFR 61.42 analysis.

Monitoring Factor 5.2: Long-Term Erosion Protection Design (Additional Considerations)

DOE relies on the erosion barrier to maintain a minimum 3 m [10 ft] clean cover to prevent intrusion into FTF waste (DOE/SRS–WD–2012–001), thereby eliminating certain shallow intrusion scenarios from analysis in DOE's PA (SRS–REG–2007–00002, Rev. 1). DOE also considers the erosion barrier part of a system of durable engineered barriers that would cause a regional driller, not accustomed to encountering hard materials to change location (SRS–REG–2007–00002, Rev. 1). For these reasons, NRC will specifically monitor use of the engineered closure cap as a barrier to intrusion. This MF can be closed after construction of the closure cap.

Monitoring Factor 5.3: Closure Cap Functions that Maintain Doses ALARA

MF 5.3 related to ALARA does not apply to the 10 CFR 61.42 evaluation.

4.6 MA 6 "Performance Assessment Maintenance"

Monitoring Factor 6.1: Scenario Analysis (Additional Considerations)

NRC will pay particular attention to DOE's consideration of various scenarios related to inadvertent intrusion into FTF components in its review of DOE's FEPs analysis (SRR–CWDA–2012–00022). NRC staff can close this MF when it concludes that DOE has adequately addressed FEPs related to inadvertent intrusion in its PA documentation.

Monitoring Factor 6.2: Model and Parameter Support

There are no special considerations under MF 6.2 for the 10 CFR 61.42 analysis.

Monitoring Factor 6.3: F-Tank Farm Performance Assessment Revisions (Additional Considerations)

NRC will evaluate DOE's revision to the FTF PA to ensure all relevant FEPs pertaining to inadvertent intrusion into FTF components were properly evaluated in the 10 CFR 61.42 analysis. This MF can be closed when NRC staff concludes that DOE has adequately evaluated FEPs important to the inadvertent intrusion analysis in its PA documentation and that its PA maintenance program is sufficient to evaluate new and significant information related to inadvertent intrusion in the future.

5 MONITORING TO ASSESS COMPLIANCE WITH 10 CFR 61.43

Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in Part 20 of this chapter, except for releases of radioactivity in effluents from the land disposal facility, which shall be governed by 10 Code of Federal Regulations (*CFR) 61.41 of this part. Every reasonable effort shall be made to maintain radiation exposures as low as is reasonably achievable (ALARA).*

The U.S. Nuclear Regulatory Commission (NRC) interprets the term "operations" as those U.S. Department of Energy (DOE) activities related to waste retrieval (i.e., heel removal), grouting, stabilization, observation, maintenance, or other similar activities. NRC intends to evaluate this performance objective (PO) from the time that DOE issues its final waste determination (WD) until the end of the institutional control period. For workers performing duties on a controlled DOE site, under DOE's radiation protection program, the 50 mSv/yr [5 rem/yr] radiation worker dose limit applies. For members of the public, including workers performing limited activities not covered under a DOE radiation protection program, the 1 mSv/yr [100 mrem/yr] dose limit for members of the public applies from sources other than effluents.[34] 10 CFR 20.1101(d) further specifies that the maximum annual dose that a member of the public can receive from airborne emissions is 0.10 mSv [10 mrem/yr]. DOE also must demonstrate that dose in any one hour in an unrestricted areas is less than 0.02 mSv [2 mrem].

DOE has a radiation protection program to ensure protection of individuals during operations. In DOE's 2010 F-Tank Farm (FTF) WD (DOE/SRS–WD-–2012–001), DOE provided a cross-walk of the relevant DOE regulation or limit consistent with that provided in 10 CFR 20 to demonstrate that the DOE regulation provides an equivalent level of protection.

During operations associated with FTF disposal at the Savannah River Site (SRS), the primary pathway of concern will be through the air. No significant releases to the subsurface or surface water from the waste in the FTF tanks are expected during the time of operations. Additionally, the release of radionuclides from FTF to the subsurface is being monitored in assessment of compliance with 10 CFR 61.41 (Chapter 3) and 10 CFR 61.42 (Chapter 4). Any leaching of contaminants from the vaults observed while the FTF is still in operation may indicate the ability of the waste form to retain the radionuclides is worse than expected and that 10 CFR 61.41 and 10 CFR 61.42 may not be met.

Importance of MA 7 "Protection of Individuals During Operations"

The Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005 (NDAA) requires NRC, in coordination with the State of South Carolina, to monitor DOE disposal actions to assess compliance with the POs in 10 CFR Part 61, Subpart C. 10 CFR 61.43 is related to protection of individuals during operations, including workers and members of the public. NRC expects the following DOE activities to incur the largest risks to workers and members of the public during FTF closure operations: (i) tank cleaning, (ii) waste stabilization, and (iii) other maintenance activities. Tank cleaning activities could include use of high pressure water that has the potential to lead to releases or radioactivity into secondary containment and the environment. Radioactivity also may be released to the tank vapor space during tank grouting activities. Modification and maintenance of tank equipment and ventilation systems are

[34]The public dose limit is 1 mSv/yr. However, 10 CFR 61.43 indicates that effluents will be addressed under 10 CFR 61.41. The 10 CFR 61.41 dose based standard is 0.25 mSv/yr [25 mrem/yr]. The point of compliance during active disposal facility operations under 10 CFR 61.41 is the larger SRS site boundary.

expected to incur worker dose. Therefore, NRC may observe installation and removal of equipment from high-level waste (HLW) tanks during an onsite observation, as practical.

NRC Monitoring Under MA7 “Protection of Individuals During Operations”

NRC staff has developed the following monitoring factors (MFs) related to protection of individuals during operations

- Protection of Workers During Operations
- Air Monitoring
- ALARA

5.1 Monitoring Factor 7.1: Protection of Workers During Operations

Compliance with the dose requirements for protection of individuals during operations is expected to be assessed by NRC through the use of dosimetry and the monitoring of radiation data and radiation records. NRC staff should review, on at least an annual basis, DOE reports and records that are related to dose during waste disposal operations to assess whether doses are within the limits found in 10 CFR Part 20 and are ALARA.

NRC staff should periodically confirm programs and policies presented in the WD (DOE/SRS–WD–2012–001) continue to be in effect during the operational period. In particular, NRC staff should verify personnel involved in waste disposal operations are provided dosimetry and are familiar with requirements of the radiation protection program. NRC will leverage staff in Region I with experience in radiation protection inspections to support onsite observations in this area. Any NRC staff participating in an onsite observation should obey DOE’s onsite radiation protection program requirements, as well as obtain dosimetry from NRC’s Office of Administration, if not already assigned, prior to the onsite observation.

This factor will be closed at the end of the assumed 100 year institutional control period or after operational doses are expected to be reduced to non-risk-significant levels following tank closure activities.

5.2 Monitoring Factor 7.2: Air Monitoring

DOE monitors air quality at SRS using air sampling stations located at the site boundary as well as in other locations throughout the site. NRC staff should review air monitoring data to determine whether activity released in the air, as a result of FTF disposal facility activities, could cause a member of the public located at the SRS site boundary to receive an annual dose of greater than 0.10 mSv/yr [10 mrem/yr] through the air pathway.

NRC staff should periodically confirm the air monitoring program continues to adequately assess the risk of FTF operations. As part of this review, NRC staff should evaluate whether sampling locations and sampling methodologies are adequate to assess airborne emissions from the FTF or rely on independent verification from the South Carolina Department of Health and Environmental Control. NRC staff expects the dose from airborne emissions to be small. If the airborne emissions dose becomes more risk significant, then NRC staff will need to evaluate the air monitoring program in greater detail.

This factor will be closed at the end of the assumed 100 year institutional control period or when operational doses are expected to be reduced to non-risk-significant levels following tank closure activities.

5.3 Monitoring Factor 7.3: As Low As Is Reasonably Achievable

The NRC regulation at 10 CFR 20.1003 defines ALARA in relevant part**:**

ALARA … means making every reasonable effort to maintain exposures to radiation as far below the dose limits … as is practical consistent with the purpose for which the … activity is undertaken…[.]

10 CFR 835 and relevant DOE Orders, which establish DOE regulatory and contractual requirements for DOE facilities and activities establish a similar requirement to 10 CFR 20.1003. DOE regulation at 10 CFR 835.2 defines ALARA as "… the approach to radiation protection to manage and control exposures (both individual and collective) to the work force and to the general public to as low as is reasonable, taking into account social, technical, economic, practical, and public policy considerations."

Furthermore, the DOE regulation at 10 CFR 835.101(c) requires the contents of each RPP to include formal plans and measures for applying the ALARA process to occupational exposure. As such, NRC staff's monitoring of ALARA under 10 CFR 61.43 will be carried out through monitoring of the Radiation Protection Program and related activities.

NRC staff should periodically (or at the appropriate time relevant to each measure) review documents associated with the following measures for ensuring ALARA (i) a documented RPP; (ii) a Documented Safety Analysis (DSA); (iii) design of the FTF; (iv) regulatory and contractual enforcement mechanisms; and (v) access controls, training, and dosimetry. These measures are described in the WD or basis document (DOE/SRS–WD–2012–001).

This factor will be closed at the end of an assumed 100 year institutional control period or when operational doses are expected to be reduced to non-risk-significant levels following tank closure activities.

6 MONITORING TO ASSESS COMPLIANCE WITH 10 CFR 61.44

The disposal facility must be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate, to the extent practicable, the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required.

These requirements relate to both stability of the disposal site and control of releases within acceptable limits. Ensuring site stability helps to minimize the access of water to the residual waste by helping to maintain the performance of the closure cap. In addition, site stability is important in protecting against inadvertent intrusion.

The monitoring area (MA) for site stability includes features, events, and processes (FEPs) that are external to the individual disposal facility components (e.g., settlement of the subsurface) that may impact individual barrier performance. FEPs that are internal to the individual components (e.g., grout shrinkage, erosion of the topsoil layer) are discussed under the respective performance objectives (POs) and MAs.

Importance of MA 8 "Site Stability"

Site stability is an integral aspect to limiting the infiltration through the disposal site and in maintaining an adequate barrier to intrusion. The key attributes responsible for providing stability of the F-Tank Farm (FTF) are the grouting of the high-level waste (HLW) tanks and annular spaces and the erosion protection designs associated with the closure cap. The U.S. Department of Energy (DOE) assumes that tank grout used to fill the tanks will create a solid monolith with little void space and eliminate differential settlement due to structural collapse of the tanks.

Site stability could be affected by settlement. Settlement could lead to cracking of the vault concrete and tank grout. Cracking is not expected to result in significant structural tank collapse; however, the integrity of the vault concrete and tank grout is important to steel liner performance and waste release, as discussed under monitoring factor (MF) 3.1. Settlement may impact the hydraulic performance of the closure cap due to (i) modifications of the closure cap slope and surface drainage patterns and (ii) disruption to closure cap components [e.g., high density polyethylene/geosynthetic clay liner (HDPE/GCL) composite layer, foundation layer, lateral drainage layer]. The erosion protection design is important in maintaining a minimum of 3 m [10 ft] of clean material above the tanks and significant ancillary equipment, which is discussed in Chapter 4.

NRC Monitoring Under MA 8 "Site Stability"

Because other MFs related to site stability are discussed in the preceding chapters, monitoring activities to assess compliance with 10 Code of Federal Regulations (CFR) 61.44 will focus on settlement.

6.1 Monitoring Factor 8.1: Settlement

Settlement could result from (i) increase in overburden from the tank grout and closure cap and (ii) the ongoing dissolution of calcareous sediment in the lower portion of the Upper Three Rivers Aquifer (UTRA) (i.e., the Santee Formation). Increased loading resulting from the increase in overburden may lead to compression of subsurface layers and consequently, differential settlement. Differential settlement has the potential to disrupt the HDPE/GCL composite layer, which acts as a significant barrier to infiltration in the early part of the performance period. Hydraulic isolation of the residual waste during this period is important in the retention of short-lived radionuclides before they are substantially decayed. Differential settlement also may affect the performance of the foundation layer and lateral drainage layer, both of which act as long-term barriers to infiltration. DOE should account for the potential effects of the additional overburden of the engineered barriers onsite stability. Technical reviews and onsite observations of settlement will be conducted by the U.S. Nuclear Regualtory Commission (NRC) staff to assess compliance with 10 CFR 61.44. Reviews will focus on (i) settlement data collected during FTF closure operations, (ii) settlement data collected from analogous sites, and (iii) updated settlement modeling investigations.

In addition to settlement from loading, settlement may result from the dissolution of calcareous sediment. Elevated bicarbonate ion concentrations and relatively high pH groundwater in and near the Santee Formation suggests ongoing dissolution of the calcareous zones within the lower zone of the UTRA (U.S. Army Corps of Engineers, 1952). Although dissolution of calcareous sediment may be a very slow process, DOE has not demonstrated that dissolution will be insignificant to site stability throughout the performance period. Such dissolution previously has created a soil structure that is characterized by arching, under-consolidation, and historic, periodic collapses. The U.S. Army Corps of Engineers (1952) identified seven surface depressions (i.e., Carolina Bays) thought to be sinks within F-Area, including one sink located within the 100 m [330 ft] compliance boundary. DOE's calculations do not account for the stability of calcareous soft zones in the Santee Formation, given the additional overburden that is to be contributed by waste-stabilizing grout and the engineered closure cap, or for additional subsidence that could occur as a result of future dissolution of subsurface material during the performance period. DOE should account for the potential effects of future dissolution of calcareous zones on ground subsidence over the long-term period of performance or demonstrate that future dissolution of calcareous sediment will be insignificant to site performance. Technical reviews related to the risk significance of calcareous zones will be conducted to assess compliance with 10 CFR 61.44. Reviews will focus on (i) processes that have resulted in the formation of sinks at the Savannah River Site (SRS) and specifically at the FTF at the General Separations Area (GSA), (ii) the potential for these processes to affect site stability throughout the performance period, and (iii) the potential dose consequences from subsidence related to dissolution of calcareous sediment. DOE stated that it will consider static-loading-induced settlement, seismically induced liquefaction and subsequent settlement, and seismic-induced slope instability in the final design of the closure cap. NRC staff will review DOE's consideration of these processes, as information is made available.

Compliance or noncompliance with the PO for 10 CFR 61.44 is associated with the status of the aforementioned monitoring activities. If surveillance, monitoring, and custodial care are carried out after closure, NRC staff expects DOE to inform it of changes to features in the immediate area that might affect site stability. These changes may include (i) vegetation denudation at the surface due to fires or storms; (ii) erosion features caused by extreme precipitation events or long-term processes; or (iii) visible surface changes due to significant biotic intrusion, earthquakes, or other geological processes.

6.2 Closure of MA 8 "Site Stability"

To assess compliance with 10 CFR 61.44, NRC staff will visually observe the facility for obvious signs of degeneration of the facility. For example, evidence of ponded water on the cap surface may be a sign of differential settlement. Surface fractures may be evidence of underlying displacement. NRC staff also may plan site visits to observe the facility after severe weather events (e.g., storms, tornados) to ascertain how well the facility can withstand these events. DOE is expected to carry out an active maintenance program for the facility through the end of the institutional control period; therefore, DOE should repair any obvious signs of facility degradation. However, such degradation can provide insights on potential long-term facility performance. NRC staff should also discuss any maintenance activities that are performed at the disposal facility (e.g., repairs to engineered surface barriers) with SCDHEC. This monitoring activity is expected to remain open indefinitely.

7 REFERENCES

Almond, P.M., D.I. Kaplan, and E.P. Shine. "Variability of Kds Values in Cementitious Materials and Sediments." Rev. 0. SRNL–STI–2011–00672. Aiken, South Carolina: Savannah River National Laboratory. 2012.

Amidon, M.B., et al. "Alternative Risk Reduction Technologies in Support of F-Tank Farm Closure." SRNL–STI–2012–00079. Aiken, South Carolina: Savannah River Site. 2012.

Cantrell, K., et al. "Plutonium Solubility Peer Review Report." LA–UR–2012–00079. Los Alamos, New Mexico: Los Alamos National Laboratory. 2011.

Demirkanli, D.I.,et al. "Modeling Long-Term Plutonium Transport in the Savannah River Site Vadose Zone." *Vadose Zone Journal*. Vol.6. pp. 344–353. 2007.

Denham, M. "Evolution of Chemical Conditions and Estimated Plutonium Solubility in the Residual Waste Layer During Post-Closure Aging of Tank 18, Savannah River National Laboratory." SRNL–STI–2012–00087. Aiken, South Carolina: Savannah River Nuclear Solutions, LLC. 2012.

Dinwiddie, C.L., D.R. Bannon, M.K. Todt, G.R. Walter, and M.M. Roberts. "Draft Fiscal Year 2012 Meso- and Intermediate-Scale Grout Monolith Test Bed Experiments: Results and Recommendations." San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses. 2012.

Dinwiddie, C.L., G.R. Walter, G. Light, S. Winterberg, D. Wyrick, D. Sims, and K. Smart. "Bonding and Cracking Behavior and Related Properties of Cementitious Grout in an Intermediate-Scale Grout Monolith." San Antonio, Texas: Center for Nuclear Waste Regulatory Analysis. 2011.

DOE/SRS–WD–2012–001, Rev. 0, "Basis for Section 3116 Determination for Closure of F-Tank Farm at Savannah River Site." Washington, DC: U.S. Department of Energy. 2012.

DOE. "Radioactive Waste Management Manual." Manual 435.1-1, Change 1. Washington DC: U.S. Department of Energy. 2001.

Davis. T.L., D.W., Tharin, D.W Jones and D.R. Lohr, "History of Waste Tank 16, 1959 Through 1974." DPSPU-77-11-17. E.I. du Pont de Nemours & Company, Savannah River Plant, July 1977.

LWO–RIP–2009–00009. "Savannah River Remediation Industrial Wastewater General Closure Plan for F-Area Waste Tank Systems." Industrial Wastewater Construction Permit 17,424–IW. Aiken, South Carolina: Savannah River Remediation, LLC. 2011.

McNatt, F.G. "History of Waste Tank 20 1959 Through 1974." DPSPU 82-10-11. Aiken, South Carolina: E.I. du Pont de Nemours & Company, Savannah River Plant. July 1982.

NRC. NUREG–1911, "NRC Periodic Compliance Monitoring Report for U.S. Department of Energy Non-High-Level Waste Disposal Actions." Rev. 3. Washington, DC: U.S. Nuclear Regulatory Commission. February 2012.

NRC. “Technical Evaluation Report for F-Area Tank Farm Facility, Savannah River Site, South Carolina—Final Report.” ML112371715. Washington, DC: U.S. Nuclear Regulatory Commission. 2011.

NRC. “U.S. Nuclear Regulatory Commission Staff Requests for Additional Information on the Draft Basis for Section 3116 Determination for Closure of F-Tank Farm at the Savannah River Site (Rev. 0) and on Performance Assessment for the F-Tank Farm for the Savannah River Site (Rev. 1).” DOE/SRS–WD–2010–001. Memorandum from L. Camper (NRC) to F. Marcinowski (DOE). ML103190402. Washington, DC: U.S. Nuclear Regulatory Commission. 2010.

NRC. NUREG–1854, “NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations—Draft Report for Interim Use.” Washington, DC: U.S. Nuclear Regulatory Commission. August 2007.

NRC. NUREG–1573, “A Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities: Recommendations of NRC’s Performance Assessment Working Group.” Washington, DC: U.S. Nuclear Regulatory Commission. October 2000.

NRC. NUREG–0945, “Final Environmental Impact Statement on 10 CFR Part 61 Licensing Requirements for Land Disposal of Radioactive Waste: Summary and Main Report.” Vol. 1. Washington DC: U.S. Nuclear Regulatory Commission. November 1982.

Prikryl, J.D. and D.A. Pickett. “Recommended Site-Specific Sorption Coefficients for Reviewing Non-High-Level Waste Determinations at the Savannah River Site and Idaho National Laboratory.” San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses. 2007.

SRR–LWP–2009–00001, Rev. 17. “Savannah River Site Liquid Waste System Plan.” Washington, DC: U.S. Department of Energy. 2012.

SRR–CWDA–2009–00054, Rev. 0. “Comment Response Matrix for Nuclear Regulatory Commission (NRC) Comments on the F-Tank Farm Performance Assessment.” Aiken, South Carolina: Savannah River Remediation LLC, Closure and Waste Disposal Authority. 2010.

SRR-CWDA-2012-00020, Rev. 0. “Savannah River Site Liquid Waste Facilities Performance Assessment Maintenance Program, FY2012 Implementation Plan,” Aiken, South Carolina: Savannah River Remediation, LLC. 2012.

SRR–CWDA–2012–00022, Rev. 0. “Evaluation of Features, Events, and Processes in the F-Area Tank Farm Performance Assessment.” Aiken, South Carolina: Savannah River Remediation, LLC. 2012.

SRS–REG–2007–00002, Rev. 1. “Performance Assessment for the F-Tank Farm at the Savannah River Site.” Aiken, South Carolina: Savannah River Remediation, LLC, Closure and Waste Disposal Authority. 2010.

SRNS–RP–2011–00995, Rev. 1. “F-Area Tank Farm Ground Water Monitoring Plan.” Aiken, South Carolina: Savannah River Nuclear Solutions, LLC. 2012.

State of South Carolina. “South Carolina Pollution Control Act.” 1985. <http://www.scstatehouse.gov/code/t48c001.php>. (22 June 2012).

U.S. Army Corps of Engineers. “Geologic Engineering Investigations.” Vicksburg, Mississippi: Waterways Experiment Station, U.S. Army Corps of Engineers. 1952.

WSRC–OS–94–42, “Federal Facility Agreement for the Savannah River Site.” Washington DC: U.S. Department of Energy. 1993.

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APPENDIX A

MONITORING FACTORS

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Table A–1. Cross-Walk Between Consultative Review Comments, Recommendations, and Monitoring Areas/Factors*

ID	Performance Objective	Recommendation or Comment	Monitoring Factor†	Risk, Difficulty, and Timing Ranking	Open Item Database (OID)‡ and/or (TER Page No.)
		MA 1 "Inventory"			
1§	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE sample each tank following waste retrieval operations for the purpose of developing a final inventory.	Factors 1.1—Final Inventory and Risk Estimates Factor 1.2—Residual Waste Sampling	Medium to High Risk Medium Difficulty As Tanks Are Cleaned	(TER Pgs. 107, 178)
2¶	10 CFR 61.41 10 CFR 61.42 Including ALARA	NRC recommends DOE better explain intratank waste variability that influences waste characterization and uncertainty evaluation. NRC's comments in this area were expressed in the context of Tank 18 sampling, but also pertain to future characterization of other tanks. Specifically, NRC commented on (i) lack of explanation regarding differences between past and current sample variability, (ii) potential lack of consideration and explanation of the unexpectedly high tank wall concentrations for Pu-238, and (iii) lack of basis for assumptions regarding normality of sample concentrations and volume estimates when calculating inventory multiplier to be used in the probabilistic analysis.	Factor 1.2—Residual Waste Sampling	Medium Risk Medium Difficulty As Tanks Are Sampled	(TER Pgs. 43, 74, 76)

Table A–1. Cross-Walk Between Consultative Review Comments, Recommendations, and Monitoring Areas/Factors* (continued)

ID	Performance Objective	Recommendation or Comment	Monitoring Factor†	Risk, Difficulty, and Timing Ranking	Open Item Database (OID)‡ and/or (TER Page No.)
3¶	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE provide evidence to support its intent to remove radionuclides from the list of nine radionuclides that were potentially considered as HRRs, based on Tanks 18 and 19's sampling results. For example, DOE could show that Tanks 18 and 19's residual waste is representative of waste in other tanks that DOE does not intend to sample for these HRRs.	Factor 1.2—Residual Waste Sampling	Low to Medium Risk Low Difficulty Before Dropping HRRs From Sampling	(TER Pg. 51)
4§	10 CFR 61.41 10 CFR 61.42 Including ALARA	NRC recommends DOE consider improvements to residual material mapping and consideration of uncertainty in volume estimates.	Factor 1.3—Residual Waste Volume	Medium Risk Medium Difficulty 1 to 5 Years	OID 41 (TER Pgs. 43, 48, 79)
5¶	10 CFR 61.41 10 CFR 61.42 Including ALARA	DOE indicates in response to NRC comment (SRR–CWDA–2009–00054, Rev. 0) its intent to verify PA assumptions regarding transfer line inventories consistent with Section 8.2, "Further Work" in DOE's PA (SRS–REG–2007–00002, Rev. 1).	Factor 1.4—Ancillary Equipment Inventory	Low to Medium Risk Low Difficulty 1 to 5 Years	(TER Pg. 49)
6§	Criterion 2—Removal to the Maximum Extent Practical 10 CFR 61.41 and 61.42 ALARA	NRC recommends DOE more fully evaluate costs and benefits of additional HRR removal, including (i) consideration of benefits of additional HRR removal over longer performance periods (and considering uncertainty in the timing of peak HRR doses), (ii) justification for assumptions regarding alternative cleaning technology effectiveness, and (iii) comparison of costs and benefits of additional HRR removal to similar DOE activities.	Factor 1.5—Waste Removal As It Pertains to ALARA	Medium Risk Medium Difficulty As Tanks Are Cleaned	(TER Pgs. 80, 81)

Table A–1. Cross-Walk Between Consultative Review Comments, Recommendations, and Monitoring Areas/Factors* (continued)

ID	Performance Objective	Recommendation or Comment	Monitoring Factor†	Risk, Difficulty, and Timing Ranking	Open Item Database (OID)‡ and/or (TER Page No.)
		MA 2 "Waste Release"			
7#	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE perform experiments to verify validity of Geochemist's Workbench calculations used to determine solubility limiting phases, solubility limits, and chemical transition times. These experiments should study (i) pH and Eh evolution of the grout pore water over time, (ii) controlling solubility limiting phases, and (iii) static and dynamic leach tests to study the mobility of HRRs, including consideration of alteration of tank residuals following chemical cleaning with reagents, such as oxalic acid.	Factor 2.1—Solubility-Limiting Phases/Limits and Validation Factor 2.2—Chemical Transition Times and Validation	High Risk Medium to High Difficulty Short- to Intermediate-Term	OID 1, 2, 8, 15, 16, and 17 (TER Pgs. 134, 178)
8¶	10 CFR 61.41 10 CFR 61.42	DOE should consider uncertainty in initial conditions and performance lifetime of FTF concrete vaults, as they impact uncertainty in the calculated steel liner failure times.	Factor 3.1—Concrete Vault Performance (As It Impacts Steel Liner Corrosion)	Medium to High Risk Medium Difficulty Long-Term Activity (need contingent on other factors)	(TER Pgs. 120–128)
9¶	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE obtain greater support for its assumption regarding flow through the tank grout (i.e., fracture versus matrix) flow as it impacts the timing of chemical transition or time to release of HRRs at risk-significant solubility. If found to be risk-significant, DOE should consider the appropriateness of using moisture characteristic curves for matrix materials to simulate fracture flow.	Factor 3.2—Grout Conditioning Factor 3.3—Shrinkage and Cracking	Medium to High Risk Medium to High Difficulty Intermediate to Long-Term (need contingent on other factors)	OID 24 and 26 (TER Pgs. 126–127)

Table A–1. Cross-Walk Between Consultative Review Comments, Recommendations, and Monitoring Areas/Factors* (continued)

ID	Performance Objective	Recommendation or Comment	Monitoring Factor†	Risk, Difficulty, and Timing Ranking	Open Item Database (OID)‡ and/or (TER Page No.)
		MA 3 "Cementitious Material Performance"			
10§	10 CFR 61.41 10 CFR 61.42	Given the wide range of values in the literature, NRC recommends DOE obtain additional support for basemat K*d*s for Pu and Np, including consideration of solubility affects from previous evaluations and representativeness of experimentally derived values for aged concrete.	Factor 3.5—Basemat Performance	Medium to High Risk Medium to High Difficulty 1 to 5 Years	OID 13, 14 and 20 (TER Pgs. 128, 178)
		MA 4 "Natural System Performance"			
11¶	10 CFR 61.41 10 CFR 61.42	NRC recommended DOE evaluate appropriateness of averaging K*d*s of multiple oxidation states to simulate the transport of Pu in the natural system.	Factor 4.1—Pu Natural Attenuation	Medium to High Risk Short-Term	OID 45 (TER Pg. 129)
12¶	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE continue to evaluate significance of calcareous zone dissolution on FTF flow and transport, including conduct of tracer studies and field mapping of seepage locations along Upper Three Runs Creek.	Factor 4.2—Calcareous Zone Characterization	Medium Risk Low to Medium Difficulty Next PA Update	OID 28 and 29 (TER Pgs. 146, 147, 149, 150, 178)
		MA 5 "Closure Cap Performance"			
13¶	10 CFR 61.41 10 CFR 61.42 10 CFR 61.44	NRC recommends DOE provide additional model support for (i) the long-term hydraulic conductivity of the upper foundation layer and lateral drainage layer and (ii) the long-term erosion of the topsoil layer.	Factor 5.1—Long-Term Hydraulic Performance of the Closure Cap Factor 5.2—Long-Term Erosion Protection Design	Low to Medium Risk Medium Difficulty Long-Term Activity	OID 5 and 6 (TER Pgs. 104, 105)
14¶	10 CFR 61.41 10 CFR 61.42 10 CFR 61.44	NRC recommends DOE conduct a preliminary evaluation of erosion protection designs (e.g., assessment of an acceptable rock source, and the ability of an integrated drainage system to accommodate design features) prior to completing the final closure cap design.	Factor 5.1—Long-Term Hydraulic Performance of the Closure Cap Factor 5.2—Long-Term Erosion Protection Design	Low to Medium Risk Low Difficulty Long-Term Activity	(TER Pgs. 104, 105)

Table A–1. Cross-Walk Between Consultative Review Comments, Recommendations, and Monitoring Areas/Factors* (continued)

ID	Performance Objective	Recommendation or Comment	Monitoring Factor†	Risk, Difficulty, and Timing Ranking	Open Item Database (OID)‡ and/or (TER Page No.)
MA 6 "Performance Assessment Maintenance"					
15§	10 CFR 61.41 10 CFR 61.42	DOE indicated in an RAI resolution meeting on June 28 2011 (Shaffner, 2011) that it would explain the differences in the inventory lists for tanks versus ancillary equipment in future PA documentation.	Factor 6.2—Model and Parameter Support	Low Risk Low Difficulty Next PA Update	(TER Pg. 49)
16§	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE perform a systematic scenario analysis in which FEPs are identified, screened, and dispositioned using transparent and traceable documentation of the FEPs considered, the screening arguments, and how FEPs are implemented in the models to support future WD efforts.	Factor 6.1—Scenario Analysis	Medium Risk Medium Difficulty Next PA Update	OID 40 (TER Pgs. 92, 93, 95, 178)
17¶	10 CFR 61.41 10 CFR 61.42	DOE should consider uncertainty in steel liner performance, including more aggressive service conditions and corrosion mechanisms than assumed in the PA, as well as a patch model for waste release, if deemed to be risk-significant.	Factor 6.2—Model and Parameter Support	Medium to High Risk Medium to High Difficulty Long-Term Activity (need contingent on other factors)	OID 7, 9, 10, 11, 12, 21, and 25 (TER Pg. 121)
1.8.3 8¶	1.8.4 1 0 CFR 61.41 1.8.5 1 0 CFR 61.42	1.8.6 NRC recommends DOE obtain additional support for probabilistic parameter distributions, including solubility limiting phases, cement K*d*s (based on sediment variability), chemical transition times, basemat bypass, and configuration probability.	1.8.7 Factor 6.2—Model and Parameter Support	1.8.8 Medium Risk Intermediate-Term	OID 18, 19, 22, 24, 46 (TER Pgs. 130–132)
19¶	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE acquire FTF specific data to support material property assignments, including hydraulic conductivity, moisture characteristic curves, and K*d*s.	Factor 6.2—Model and Parameter Support	Low to Medium Risk Long-Term	(TER Pgs. 128–129)

Table A–1. Cross-Walk Between Consultative Review Comments, Recommendations, and Monitoring Areas/Factors* (continued)

ID	Performance Objective	Recommendation or Comment	Monitoring Factor†	Risk, Difficulty, and Timing Ranking	Open Item Database (OID)‡ and/or (TER Page No.)
20#	10 CFR 61.41 10 CFR 61.42	NRC will monitor DOE's efforts to study the impact of cement leachate on radionuclide mobility.	Factor 6.2—Model and Parameter Support	Low to Medium Risk Long-Term	OID 32 (TER Pg. 126)
21¶	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE address the significant amount of dispersion evident in its near-field and far-field PORFLOW models, including evaluation of the need for mesh refinement to ensure that contaminant plumes are not artificially dispersed over the volume of the cells in the far-field model. Nonphysical dispersion may be attributable to large changes in adjacent element size and large differences in element sizes between the vadose zone and far-field models. DOE should evaluate the adequacy of the time discretization of the model(s) for swiftly moving constituents such as Tc-99.	Factor 6.2—Model and Parameter Support	Medium Risk Low to Medium Difficulty Next PA Update	OID 34 (TER Pgs. 149–150)
22¶	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE evaluate appropriateness of the assumed level of physical dispersion in the FTF model (longitudinal and transverse vertical).	Factor 6.2—Model and Parameter Support	Medium Risk Low to Medium Difficulty Next PA Update	OID 31 and 34 (TER Pgs. 149, 179)
23¶	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE provide greater transparency and traceability of far-field model calibration, including consideration of more extensive calibration focused strictly on the area of interest.	Factor 6.2—Model and Parameter Support	Medium Risk Medium to High Difficulty Next PA Update	OID 35 (TER Pg. 178)
24¶	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE evaluate compliance with POs in 10 CFR Part 61, Subpart C at the point of maximum exposure in the UTRA.	Factor 6.2—Model and Parameter Support	Medium Risk Low difficulty Next PA Update	OID 33 (TER Pgs. 147–148)

Table A–1. Cross-Walk Between Consultative Review Comments, Recommendations, and Monitoring Areas/Factors* (continued)

ID	Performance Objective	Recommendation or Comment	Monitoring Factor†	Risk, Difficulty, and Timing Ranking	Open Item Database (OID)‡ and/or (TER Page No.)
25¶	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE evaluate plant transfer factor uncertainty in future updates to its PA. DOE should consider the appropriateness of excluding common vegetable types in its assignment of plant transfer factors (DOE only considers root vegetable data) based on production data rather than household data that might be more appropriate for a resident gardener.	Factor 6.2—Model and Parameter Support	Low to Medium Risk Medium difficulty Next PA Update	OID 43 (TER Pg. 153)
26¶	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE evaluate appropriateness of assumptions related to drinking water consumption in future updates to its PA, such as partitioning consumption rates based on use of both bottled and community water. Biosphere parameters should be reasonably conservative and reflect the behavior of the average member of the critical group.	Factor 6.2—Model and Parameter Support	Low to Medium Risk Low Difficulty Next PA Update	OID 44 (TER Pgs. 153–154)
27¶	10 CFR 61.41 10 CFR 61.42	DOE should better assess uncertainty in the timing of peak dose, given the inherent level of uncertainty associated with predicting doses over tens of thousands of years; key parameters, such as steel liner failure times and chemical transition times may be overly constrained.	Factor 6.2—Model and Parameter Support	Medium to High Risk Medium Difficulty Next PA Update	OID 18 and 46 (TER Pgs. 167, 168, 169)
28¶	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE provide additional support for the likelihood of its base case or expected Case A.	Factor 6.2—Model and Parameter Support	Medium to High Risk Medium to High Difficulty Next PA Update	OID 39 and 46 (TER Pgs. 167, 168, 170)
29¶	10 CFR 61.41 10 CFR 61.42	NRC recommends DOE improve transparency and documentation of its benchmarking process. NRC recommends DOE apply a more methodical and systematic approach to the benchmarking process in future updates to its PA.	Factor 6.2—Model and Parameter Support	Medium Risk Medium Difficulty Next PA Update	OID 34 (TER Pg. 171)

Table A–1. Cross-Walk Between Consultative Review Comments, Recommendations, and Monitoring Areas/Factors* (continued)

ID	Performance Objective	Recommendation or Comment	Monitoring Factor†	Risk, Difficulty, and Timing Ranking	Open Item Database (OID)‡ and/or (TER Page No.)
30¶	10 CFR 61.41 10 CFR 61.42	NRC suggests DOE consider consistency between the plotting interval and calculation time step size. DOE should correct errors in its probabilistic assessment (e.g., porosity of 1E–20). DOE also should present results for the point of maximum exposure.	Factor 6.2—Model and Parameter Support	Low to Medium Risk Low Difficulty Next PA Update	(TER Pgs. 147–148)
31¶	10 CFR 61.41 10 CFR 61.42	NRC made a general comment that DOE could improve its parameter distribution assignments, hybrid modeling approach, benchmarking process, and evaluation and interpretation of probabilistic modeling results. With respect to parameter distributions, NRC included several items in its open items database, most of which are listed in other recommendations, with the exception of probability of basemat bypass flow.	Factor 6.2—Model and Parameter Support	Medium Risk Medium Difficulty Next PA Update	OID 22, 23 and 39 (TER Pg. 151)
MA 7 "Protection of Individuals During Operations"					
32¶	10 CFR 61.43	DOE can demonstrate compliance with protection of individuals during operations.	Factor 7.1—Protection of Workers During Operations Factor 7.2—Air Monitoring	Low Risk Low to Medium Difficulty Ongoing	(TER Pg. 174)
MA 8 "Site Stability"					
33¶	10 CFR 61.44	NRC recommends DOE continue to evaluate closure cap settlement and stability, including consideration of (i) increased overburden from the tank grout and closure cap on settlement and (ii) potential for subsidence associated with ongoing dissolution of calcareous sediment in the Santee Formation.	Factor 8.1—Settlement	Medium Risk Medium to High Difficulty 1 to 5 years	OID 30 (TER Pg. 176)

Table A–1. Cross-Walk Between Consultative Review Comments, Recommendations, and Monitoring Areas/Factors* (continued)

ID	Performance Objective	Recommendation or Comment	Monitoring Factor†	Risk, Difficulty, and Timing Ranking	Open Item Database (OID)‡ and/or (TER Page No.)
34¶	10 CFR 61.44	NRC concluded that assumed long-term compressive strength of the grout monolith is not adequately supported and may be optimistic based on observations of vault cracks, discussed in TER Section 4.2.9.1 (NRC, 2011). While cracking of the vault concrete and tank grout is not expected to result in significant structural tank collapse, the integrity of the vault concrete and tank grout is important to steel liner performance and waste release.	Factor 8.1—Settlement	Medium Risk Medium to High Difficulty 1 to 5 Years	
Other TER Recommendations					
35¶	Criterion 2—Technology Selection	NRC recommends DOE specifically consider and evaluate HRR removal in its technology selection and effectiveness evaluations consistent with the NDAA.	TER Recommendation Only	NA	(TER Pgs. 55, 56, 79)
36¶	Criterion 2—Technology Selection	NRC recommends DOE continuously evaluate new technologies, participate in technology exchanges, and not default to previous evaluations for technology selection.	TER Recommendation Only	NA	(TER Pgs. 77, 78, 79)
37¶	Criterion 2—Removal to the Maximum Extent Practical	NRC recommends DOE include more specificity in its process for determining HRRs are removed to the maximum extent practical, including (i) defining the term end states versus removal goals and (ii) clarifying when conditions are sufficiently similar to warrant use of a previous technology evaluation.	TER Recommendation Only	NA	(TER Pg. 79)

Table A–1. Cross-Walk Between Consultative Review Comments, Recommendations, and Monitoring Areas/Factors* (continued)

ID	Performance Objective	Recommendation or Comment	Monitoring Factor†	Risk, Difficulty, and Timing Ranking	Open Item Database (OID)‡ and/or (TER Page No.)
38¶	Criterion 2—Removal to the Maximum Extent Practical	NRC recommends DOE more fully evaluate or document its consideration of alternatives to additional HRR removal, including (i) modifications to existing technologies (e.g., upgraded Mantis or enhanced chemical cleaning); (ii) modification to tank system components (e.g., installation of a new risers or removal of equipment from existing risers); (iii) sequential cleaning (e.g., sequencing of mechanical and chemical technologies in Tank 18); and (iv) alternative cleaning technologies (e.g., alternative reagents to leach HRRs out of residual heels).	TER Recommendation Only	NA	(TER Pgs. 79, 81)
39¶	Criterion 2—Removal to the Maximum Extent Practical	NRC recommends DOE better quantify technology effectiveness. For example, DOE should better characterize waste and residual tank inventory prior to deployment of cleaning technologies to better assess effectiveness.	TER Recommendation Only	NA	(TER Pgs. 77, 79)

ALAR–As Low As Is Reasonably Achievable, DOE–The U.S. Department of Energy, FTF–F-Tank Farm, HRR–Highly Radioactive Radionuclide, NRC–The U.S. Nuclear Regulatory Commission, PA–Performance Assessment, RAI–Request for Additional Information, TER–Technical Evaluation Report, UTRA–Upper Three Rivers Aquifer

*The table is organized by Monitoring Area. The cross-walk from the consultative recommendation/comment to MFs is provided in the column "Monitoring Factor."
†NRC notes that NRC monitoring pertains to assessment of compliance with the POs in 10 CFR Part 61, Subpart C. Thus, comments or recommendations related to the NDAA criterion that waste has had HRR removed to the maximum extent practical or what NRC refers to as Criterion 2 under the NDAA is only monitored if the same comment or recommendation applies to the ability of the disposal facility to meet Criterion 3, compliance with the POs in 10 CFR Part 61, Subpart C, including the ALARA requirements found in 10 CFR 61.41 and 61.43. If Criterion 2 recommendations in NRC's TER are not tied to Criterion 3, such as ALARA, then the TER recommendations are not carried forward into monitoring.
‡Table in Appendix B.
§Listed in DOE'S PA Maintenance Plan.
¶Not currently listed in DOE's PA Maintenance Plan or not executed. Issue is still risk-significant and outstanding without a path forward to address.
#Listed in DOE'S PA Maintenance Plan or DOE already executed the recommendation, but preliminary indications suggest that the proposal or results may be lacking.

SRR–CWDA–2009–00054. "Comment Response Matrix for Nuclear Regulatory Commission (NRC) Comments on the F-Tank Farm Performance Assessment." Aiken, South Carolina: Savannah River Remediation, LLC, Closure and Waste Disposal Authority. 2010.
SRS–REG–2007–00002. Rev. 1. "Performance Assessment for the F-Tank Farm at the Savannah River Site." Aiken, South Carolina: Savannah River Remediation, LLC, Closure and Waste Disposal Authority. 2010.

Shaffner, J. "Summary of Teleconference Between U.S. Nuclear Regulatory Commission Staff and U.S. Department of Energy Representatives Concerning Responses to RAIs Related to Closure of F-Tank Farm, Savannah River Site." Memorandum to File PROJ0734. ML111920367. Washington, DC: U.S. Nuclear Regulatory Commission. 2011.

Table A–1. Cross-Walk Between Consultative Review Comments, Recommendations, and Monitoring Areas/Factors* (continued)

ID	Performance Objective	Recommendation or Comment	Monitoring Factor†	Risk, Difficulty, and Timing Ranking	Open Item Database (OID)‡ and/or (TER Page No.)
NRC. "Technical Evaluation Report for F-Area Tank Farm Facility, Savannah River Site, South Carolina—Final Report." ML112371715. Washington, DC: U.S. Nuclear Regulatory Commission. 2011.					

Table A–2. Grouping of NRC's Performance Assessment Maintenance Items in Table A–1 and Cross-Walk to DOE's Performance Assessment Maintenance Plan

Recommendation or Comment	Performance Objective	TER Section	DOE PA Maintenance Program Section
3.1—Scenario Analysis			
NRC recommends DOE perform a systematic scenario analysis in which DOE identifies, screens, and dispositions FEPs using transparent and traceable documentation of the FEPs considered, the screening arguments, and how FEPs are implemented in the models to support future WD efforts.	61.41 61.42	4.2.3 4.2.3.2 4.4 (pgs. 92, 93, 95, 178)	SRR–CWDA–2012–00022
3.2—Model and Parameter Justification			
DOE indicated in an RAI resolution meeting on June 28, 2011 (Shaffner, 2011), that it would explain the differences in the inventory lists for tanks versus ancillary equipment in future PA documentation.	61.41 61.42	3.2.3 (pg. 49)	
Uncertainty in steel liner performance, including more aggressive service conditions and corrosion mechanisms than assumed in the PA should be considered, as well as a patch model for waste release, if deemed to be risk-significant.	61.41 61.42	4.2.9.2 (pg 121)	
NRC recommends DOE obtain additional support for probabilistic parameter distributions, including solubility limiting phases, cement K*d*s (based on sediment variability), chemical transition times, basemat bypass, and configuration probability.	61.41 61.42	4.2.9.4 (pgs. 130–132)	FY12: 2.3.1.2, 2.3.1.7
NRC recommends DOE acquire FTF specific data to support material property assignments, including hydraulic conductivity, moisture characteristic curves, and K*d*s.	61.41 61.42	4.2.9.4 (pgs. 128–130)	2.3.1.2, 2.3.1.7, 2.3.2.1, 2.3.2.2, 2.3.3, 2.3.4.2
NRC will monitor DOE's efforts to study the impact of cement leachate on radionuclide mobility.	61.41 61.42	4.2.9.3 (pg. 126)	SRNL–STI–2011–00672 (Almond, et al., 2012)
NRC recommends DOE investigate the significant amount of dispersion in its near-field and far-field models that may be attributable to large changes in adjacent element size and large difference in element sizes between the vadose zone and far-field models. DOE also should evaluate the adequacy of the time discretization for swiftly moving constituents, such as Tc-99.	61.41 61.42	4.2.11.5 4.2.11.6 (pgs. 148–150)	FY12: 3.2.2
NRC recommends DOE evaluate the appropriateness of the assumed level of physical dispersion in the FTF model (longitudinal and transverse vertical).	61.41 61.42	4.2.11.6 4.4 (pgs. 149, 179)	FY12: 3.2.2
NRC recommends DOE provide greater transparency and traceability of far-field calibration, including consideration of more extensive calibration focused on the area of interest.	61.41 61.42	4.4 (pg. 178)	FY12: 3.2.2

Table A–2. Grouping of NRC's Performance Assessment Maintenance Items in Table A–1 and Cross-Walk to DOE's Performance Assessment Maintenance Plan (continued)

Recommendation or Comment	Performance Objective	TER Section	DOE PA Maintenance Program Section
NRC recommends DOE evaluate compliance with the POs in 10 CFR Part 61, Subpart C, at the point of maximum exposure in the UTRA.	61.41 61.42	4.2.11.4 (pgs. 147–148)	
NRC recommends DOE evaluate plant transfer factor uncertainty in future updates to its PA. DOE should consider appropriateness of excluding common vegetable types in its assignment of plant transfer factors (DOE only considers root vegetable data) based on production data rather than household data that might be more appropriate for a resident gardener.	61.41 61.42	4.2.17 (pg. 153)	
NRC recommends DOE evaluate appropriateness of assumptions related to drinking water consumption in future updates to its PA, such as partitioning consumption rates based on use of both bottled and community water. Biosphere parameters should be reasonably conservative and reflect behavior of the average member of the critical group.	61.41 61.42	4.2.17 (pgs. 153-154)	
DOE should better assess uncertainty in the timing of peak dose, given the inherent level of uncertainty associated with predicting doses over tens of thousands of years; key parameters, such as steel liner failure times and chemical transition times, may be overly constrained.	61.41 61.42	4.2.19 (pgs. 167–169)	
NRC recommends DOE provide additional support for the likelihood of its base case or expected Case A.	61.41 61.42	4.2.19 4.2.19.1 4.2.19.2 (pgs. 167–168, 170)	
NRC recommends DOE improve the transparency and documentation of its benchmarking process. NRC recommends DOE perform a more methodical and systematic approach to applying the benchmarking process in future updates to its PA.	61.41 61.42	4.2.19.3 (pg. 171)	
NRC suggests DOE consider consistency between the plotting interval and calculation time step size. DOE should correct errors in its probabilistic assessment (e.g., porosity of 1E–20). DOE also should present results for the point of maximum exposure.	61.41 61.42	4.2.19.34.2.19.4 (pgs. 170–171)	
NRC made a general comment that DOE could improve its parameter distribution assignments, hybrid modeling approach, benchmarking process, and evaluation and interpretation of probabilistic modeling results. With respect to parameter distributions, NRC included several items in its open items database, most of which are listed in other recommendations, with the exception of probability of basemat bypass.	61.41 61.42	4.2.19 4.4 (pg. 171)	

DOE–The U.S. Department of Energy, FEP–Features, Events, and Processes, FTF–F-Tank Farm, K*d*s –Distribution Coefficients, NRC–The U.S. Nuclear Regulatory Commission, PA–Performance Assessment, PO–Performance Objective, RAI–Request for Additional Information, TC–Techneium, UTRA–Upper Three Rivers Aquifer, WD–Waste Determination

Table A–2. Grouping of NRC's Performance Assessment Maintenance Items in Table A–1 and Cross-Walk to DOE's Performance Assessment Maintenance Plan (continued)

Recommendation or Comment	Performance Objective	TER Section	DOE PA Maintenance Program Section

Almond, P.M., D.I. Kaplan, and E.P. Shine. "Variability of Kd Values in Cementitious Materials and Sediments." Rev. 0. SRNL–STI–2011–00672. Aiken, South Carolina: Savannah River National Laboratory. 2012.

SRR–CWDA–2009–00054, Rev. 0. "Comment Response Matrix for Nuclear Regulatory Commission (NRC) Comments on the F-Tank Farm Performance Assessment." Aiken, South Carolina: Savannah River Remediation LLC, Closure and Waste Disposal Authority. 2010.

SRR–CWDA–2012–00022. "Evaluation of Features, Events, and Processes in the F-Area Tank Farm Performance Assessment. Rev.0." Aiken, South Carolina: Savannah River Remediation, LLC. 2012.

Shaffner, J. "Summary of Teleconference Between U.S. Nuclear Regulatory Commission Staff and U.S. Department of Energy Representatives Concerning Responses to RAIs Related to Closure of F-Tank Farm, Savannah River Site." Memorandum to File PROJ0734. ML111920367. Washington, DC: U.S. Nuclear Regulatory Commission. 2011.

APPENDIX B

OPEN ITEMS DURING CONSULTATION

Table B–1. Open Items Database Data Transmitted to DOE Via Meeting Summary Held on February 17, 2011 (NRC, 2011)

ID	Open Item	Related Comment	Technical Category	Priority	Resolution Difficulty	Technical Subcategory	NRC Recommendation(s) to DOE	Status Table A–1 ID
1	Identify Tc solubility limiting phases	RAI–NF–8 RAI–NF–9	Near-field	1	1	Solubility–CZ	Identify solid phase key radionuclides are associated within various sludge types (sequential extractions or other methods). Conduct solubility studies on tank sludges. Characterize mineralogy of various sludge types in SRS tanks.	Open 7
2	Identify Pu solubility limiting phases	RAI–NF–8 RAI–NF–9	Near-field	1	1	Solubility–CZ	Identify solid phase key radionuclides are associated within various sludge types (sequential extractions or other methods). Conduct solubility studies on tank sludges. Characterize mineralogy of various sludge types in SRS tanks.	Open 7
5	Infilling of lateral drainage layer with coarser sediments	RAI–IE–2	Infiltration	2	2	Cap	Rerun basecase with more technically defensible parameters, given current knowledge base. Conduct literature review. Look at natural analogs.	Open 13
6	Basis for reduced infiltration rate, due to residual cap performance	RAI–IE–3	Infiltration	2	2	Cap	Rerun basecase with more technically defensible parameters, given current knowledge base	Open 13
7	As-emplaced versus assumed cap performance	CC–IE–1	Infiltration	3	2	Cap	Rerun basecase with more technically defensible parameters, given current knowledge base	Closed
8	Longevity of reducing conditions	RAI–NF–1	Near-field	1	1	Solubility–CZ	Conduct experiments to study the conditioning of SRS groundwaters in cements w/varying levels of degradation	Open 7
9	General versus localized corrosion, as dominant mechanism	RAI–NF–2	Near-field	1	2	Steel Liner	Collect analog data on carbon steel in contact with cement. Conduct experiments to study impact of various hydrologic configurations on corrosion rates [fully immersed, partially immersed (corrosion at liquid/air interface), wet/dry cycling]. Conduct accelerated corrosion experiments with carbon steel in contact with cements of varying levels of degradation. Rerun basecase with more technically defensible parameters, given current knowledge base. Conduct literature review.	Open 17

Table B–1. Open Items Database Data Transmitted to DOE Via Meeting Summary Held on February 17, 2011 (NRC, 2011) (continued)

ID	Open Item	Related Comment	Technical Category	Priority	Resolution Difficulty	Technical Subcategory	NRC Recommendation(s) to DOE	Status Table A–1 ID
10	Time invariant and low diffusion coefficients for CO2 (carbonation) and O2 (after chloride-induced corrosion)	RAI–NF–3 RAI–NF–13	Near-field	1	2	Steel Liner	Collect analog data on carbon steel in contact with cement. Conduct experiments to study impact of various hydrologic configurations on corrosion rates [fully immersed, partially immersed (corrosion at liquid/air interface), wet/dry cycling]. Conduct accelerated corrosion experiments with carbon steel in contact with cements of varying levels of degradation. Rerun basecase with more technically defensible parameters, given current knowledge base. Conduct literature review.	Open 17
11	Assumption that corrosion only proceeds from one-side	RAI–NF–4	Near-field	2	2	Steel Liner	Rerun basecase with more technically defensible parameters, given current knowledge base.	Open 17
12	Wet-dry cycling of tank bottoms	RAI–NF–13	Near-field	1	1	Steel Liner	Collect analog data on carbon steel in contact with cement. Conduct experiments to study impact of various hydrologic configurations on corrosion rates [fully immersed, partially immersed (corrosion at liquid/air interface), wet/dry cycling]. Rerun basecase with more technically defensible parameters, given current knowledge base.	Open 17
13	Pu K_ds in middle-aged and old-aged cementitious materials (basemat)–solubility limited	RAI–NF–7	Near-field	2	2	Basemat	Rerun basecase with more technically defensible parameters, given current knowledge base. Conduct additional experiments to study sorption of key radionuclides to basemat. Provide additional information justifying the approach. Conduct literature review.	Open 10
14	Np K_ds in middle-aged and old-aged cementitious materials (basemat)–	RAI–NF–7	Near-field	2	2	Basemat	Rerun basecase with more technically defensible parameters, given current knowledge base. Conduct additional experiments to study sorption of key radionuclides to basemat. Provide additional information justifying the approach. Conduct	Open 10

Table B–1. Open Items Database Data Transmitted to DOE Via Meeting Summary Held on February 17, 2011 (NRC, 2011) (continued)

ID	Open Item	Related Comment	Technical Category	Priority	Resolution Difficulty	Technical Subcategory	NRC Recommendation(s) to DOE	Status Table A–1 ID
	solubility limited						literature review.	
15	Consideration of a more mobile fraction of Tc in CZ	RAI–NF–8	Near-field	1	1	Solubility–CZ	Identify solid phase key radionuclides are associated within various sludge types (sequential extractions or other methods). Conduct solubility studies on tank sludges. Include additional complexity in modeling. Rerun models. Abstract process level model.	Open 7
16	Consideration of a more mobile fraction of Pu in CZ	RAI–NF–8	Near-field	1	1	Solubility–CZ	Identify solid phase key radionuclides are associated within various sludge types (sequential extractions or other methods). Conduct solubility studies on tank sludges. Include additional complexity in modeling. Rerun models. Abstract process level model.	Open 7
17	Possibility of radionuclide release during iron phase transitions (from magnetite to hematite)	RAI–NF–9	Near-field	1	1	Solubility–CZ	Identify solid phase key radionuclides are associated within various sludge types (sequential extractions or other methods). Conduct solubility studies on tank sludges. Characterize mineralogy of various sludge types in SRS tanks. Rerun basecase with more technically defensible parameters, given current knowledge base.	Open 7
18	Support for parameter distributions related to chemical transition times	RAI–NF–10	Near-field	1	1	Solubility–CZ	Conduct experiments to study the conditioning of SRS groundwaters in cements w/ varying levels of degradation. Expert elicitation on chemical transition times.	Open 7
19	Support for likelihood of solubility limiting phases	RAI–NF–11	Near-field	1	1	Solubility–CZ	Conduct solubility studies on tank sludges. Expert elicitation on probability of various solubility limiting phases. Rerun basecase with more technically defensible parameters, given current knowledge base. Conduct literature review.	Open 18
20	Support for use of young cements (40-year old) in K_ds testing for basemats	RAI–NF–12	Near-field	2	2	Basemat	Provide additional information justifying the approach	Open 10

Table B–1. Open Items Database Data Transmitted to DOE Via Meeting Summary Held on February 17, 2011 (NRC, 2011) (continued)

ID	Open Item	Related Comment	Technical Category	Priority	Resolution Difficulty	Technical Subcategory	NRC Recommendation(s) to DOE	Status Table A–1 ID
21	Groundwater in-leakage into tanks, leading to unconditioned water and conditions closer to carbon steel in contact with soil	RAI–NF–13	Near-field	1	2	Steel Liner	Collect analog data on carbon steel in contact with cement. Conduct experiments to study impact of various hydrologic configurations on corrosion rates [fully immersed, partially immersed (corrosion at liquid/air interface), wet/dry cycling]. Conduct experiments to study the conditioning of SRS groundwaters in cements w/varying levels of degradation.	Open 17
22	Basis for probability of basemat bypass	RAI–NF–14	Near-field	1	2	Basemat	Rerun basecase with more technically defensible parameters, given current knowledge base. Provide additional information justifying the approach.	Open 36
23	Basis for lack of consideration of basemat bypass in basecase	RAI–NF–14	Near-field	1	2	Basemat	Rerun basecase with more technically defensible parameters, given current knowledge base. Provide additional information justifying the approach.	Open 31
24	Probability and consequences of a Condition 2 waste release scenario	RAI–NF–15 CC–NF–10	Near-field	1	2	Waste Release	Expert elicitation on probability of various configurations of tank system evolution. Rerun basecase with more technically defensible parameters, given current knowledge base.	Open 9
25	Consequences of early release due to partial failure of steel liner	RAI–NF–16	Near-field	1	1	Waste Release	Rerun basecase with more technically defensible parameters, given current knowledge base. Include additional complexity in modeling. Rerun models. Abstract process level model.	Open 17
26	Lack of support for moisture characteristic curves	CC–NF–9	Near-field	2	2	Waste Release	Rerun basecase with more technically defensible parameters, given current knowledge base.	On Hold 9
27	Impact of upwards diffusion in tank grout to results; in-tank hydraulics (diffusion or advection dominated)	RAI–NF–10	Near-field	2	2	Waste Release	Provide additional modeling results and evaluation	Closed

Table B–1. Open Items Database Data Transmitted to DOE Via Meeting Summary Held on February 17, 2011 (NRC, 2011) (continued)

ID	Open Item	Related Comment	Technical Category	Priority	Resolution Difficulty	Technical Subcategory	NRC Recommendation(s) to DOE	Status Table A–1 ID
28	Impact of calcareous zone dissolution on flow	RAI–FF–1	Far-field	2	2	Saturated Zone	Provide additional information justifying the approach. Include additional complexity in modeling. Rerun models. Abstract process level model. Perform tracer tests at the seepline.	Open 12
29	Impact of calcareous zone dissolution on transport	RAI–FF–1	Far-field	2	2	K_ds -Saturated Zone	Sorption experiments with groundwater in contact with calcareous zone sediments. Perform additional sorption studies to study Pu speciation & transport in the subsurface. Provide additional information justifying the approach. Perform geochemical modeling.	Open 12
30	Impact of calcareous zone on site stability	RAI–SS–3	Site Stability	2	2	Site Stability	Provide additional information justifying the approach. Include additional complexity in modeling. Rerun models. Abstract process level model.	Open 33
31	Verify PORFLOW has an acceptable amount of hydrodynamic and numerical dispersion	RAI–FF–3	Far-field	2	2	Saturated Zone	Rerun basecase with more technically defensible parameters, given current knowledge base. Provide additional information justifying the approach. Sensitivity analysis to determine risk-significance.	Open 22
32	Impact of grout leaching on saturated zone transport	RAI–FF–4	Far-field	2	2	K_ds -Saturated Zone	Provide additional information justifying the approach. Include additional complexity in modeling. Rerun models. Abstract process level model.	Open 20
33	Adequacy of the 100 m point of compliance	RAI–FF–5	Far-field	2	3	Saturated Zone	Provide additional information justifying the approach. Provide additional modeling results and evaluation.	Changed 24
34	Benchmarking issues (indicates PORFLOW results may be biased low); dispersivities	RAI–FF–3 RAI–FF–6	Far-field	2	2	Saturated Zone	Rerun basecase with more technically defensible parameters, given current knowledge base. Provide additional information justifying the approach. Include additional complexity in modeling. Rerun models. abstract process level model. Provide additional modeling results and evaluation.	Open 22 and 34

Table B–1. Open Items Database Data Transmitted to DOE Via Meeting Summary Held on February 17, 2011 (NRC, 2011) (continued)

ID	Open Item	Related Comment	Technical Category	Priority	Resolution Difficulty	Technical Subcategory	NRC Recommendation(s) to DOE	Status Table A–1 ID
35	Hydrogeological conceptual model uncertainty (vertical gradients, groundwater flow divide)	CC–FF–11	Far-field	2	3	Saturated Zone	Provide additional information justifying the approach. Sensitivity analysis to determine risk significance. Provide additional modeling results and evaluation.	Open 23
36	C-14 K_ds in the saturated zone (used higher K_ds for batch experiments at longer equilibration times)	CC–FF–7	Far-field	3	2	K_ds -Saturated Zone	Rerun basecase with more technically defensible parameters, given current knowledge base. Provide additional information justifying the approach.	Closed
37	Np K_ds in the saturated zone (higher for sand, lower for clay); clarify ranges used in PA	CC–FF–8	Far-field	3	2	K_ds -Saturated Zone	Rerun basecase with more technically defensible parameters, given current knowledge base. Provide additional information justifying the approach. Sensitivity analysis to determine risk-significance.	Closed
38	Location of clays in the SZ; impact of clay K_ds assignments on results	CC–FF–6	Far-field	2	3	K_ds -Saturated Zone	Rerun basecase with more technically defensible parameters, given current knowledge base. Provide additional information justifying the approach. Sensitivity analysis to determine risk-significance.	Closed
39	Conservatism of basecase in the face of large uncertainty	RAI–PA–1	Performance Assessment	1	1	Performance Assessment	Peer review of DOE's basecase configuration	Open 28 and 31
40	Identification of FEPs	RAI–PA–2	Performance Assessment	2	1	Performance Assessment	Conduct literature review	Open 16
41	Basis for inventory uncertainty	CC–IN–1	Uncertainty	3	3	Uncertainty	Provide additional information justifying the approach. Collect sampling data.	Open 1, 2, 3, 4

Table B–1. Open Items Database Data Transmitted to DOE Via Meeting Summary Held on February 17, 2011 (NRC, 2011) (continued)

ID	Open Item	Related Comment	Technical Category	Priority	Resolution Difficulty	Technical Subcategory	NRC Recommendation(s) to DOE	Status Table A–1 ID
42	Support for barriers to intrusion over 10,000 year compliance period	CC–IT–1	Intruders	2	3	Intruders	Provide additional information justifying the approach	Closed
43	Lack of consideration of uncertainty in transfer factors/basis for selection of basecase values	RAI–IT–1 RAI–IT–2	Intruders	2	2	Biosphere Parameter	Rerun basecase with more technically defensible parameters, given current knowledge base. Provide additional information justifying the approach. Conduct literature review. Sensitivity analysis to determine risk significance.	Open 5
44	Drinking water ingestion rates	RAI–IT–3	Intruders	3	3	Biosphere Parameter	Rerun basecase with more technically defensible parameters, given current knowledge base. Provide additional information justifying the approach. Conduct literature review.	Open 26
45	Pu K_ds in the saturated zone	CC–FF–9	Far-field	1	1	K_ds -Saturated Zone	Sorption experiments with groundwater in contact with calcareous zone sediments. Perform additional sorption studies to study Pu speciation & transport in the subsurface. Increase complexity of Pu transport modeling (e.g., consider various fractions of varying mobility and reactive transport). Include additional complexity in modeling. Rerun models. Abstract process level model.	Open 11
46	Configuration development, configuration probabilities	RAI–UA–1	Performance Assessment	1	1	Performance Assessment	Expert elicitation on probability of various configurations of tank system evolution	Open 27 and 28
47	Uncertainty in timing versus magnitude of peak dose	RAI–UA–2	Uncertainty	3	3	Uncertainty	Provide additional modeling results and evaluation	Closed
48	Configurations E and F (consider in the basecase)	RAI–UA–4	Uncertainty	2	3	Uncertainty	Provide additional modeling results and evaluation	Open 18

Table B–1. Open Items Database Data Transmitted to DOE Via Meeting Summary Held on February 17, 2011 (NRC, 2011) (continued)

ID	Open Item	Related Comment	Technical Category	Priority	Resolution Difficulty	Technical Subcategory	NRC Recommendation(s) to DOE	Status Table A–1 ID
49	Intruder sensitivity analysis	CC–IT–2 CC–IT–3	Intruders	2	3	Intruders	Provide additional information justifying the approach. Sensitivity analysis to determine risk significance. Provide additional modeling results and evaluation	Closed

FEP–Features, Events, and Processes, K*d*s –Distribution Coefficients, RAI–Requests for Additional Information, SRS–Savannah River Site, Tc–Technetium

NRC. “Summary of Teleconference Between the U.S. Nuclear Regulatory Commission Staff and the U.S. Department of Energy Representatives Concerning Requests for Additional Information Pertaining to the Draft Waste Determination and Related Performance Assessment Related to the Closure of the F-Area Tank Farm at the Savannah River Site.” Note to File (15 March 2011) From J. Shaffner (NRC). ML110700511. Washington, DC: U.S. Nuclear Regulatory Commission. 2011.

APPENDIX C

MA 2 “WASTE RELEASE”

APPENDIX C
Monitoring Area (MA) 2 "WASTE RELEASE"

The Department of Energy (DOE) relies on solubility controls in the residual waste to constrain aqueous phase concentrations of highly radioactive radionuclides (HRRs) released from the waste tanks and associated groundwater doses to a potential receptor. In DOE's performance assessment (PA), solubility limiting phases and the resulting solubility limits are often a function of the chemical environment in the contaminated zone. The chemical environment of the contaminated zone is affected by chemical conditioning from the overlying grout, which is intended to ensure a high pH and low Eh chemical environment in the contaminated zone for thousands to tens of thousands of years, thereby delaying significant release of key HRRs beyond the 10,000-year period of performance.

In its technical evaluation report (TER) (NRC, 2011), the Nuclear Regulatory Commission (NRC) staff presented a number of observations and recommendations. Staff's primary recommendation related to Criterion 3, as stated in the Executive Summary, is as follows:

> NRC staff recommends DOE conduct waste release experiments to increase support for key modeling assumptions related to: (i) the evolution of pH and Eh in the grouted tank system over time; (ii) identification of HRR association with solid phases comprising the residual wastes; and (iii) 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 (POs) 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, DOE should initiate discussions with NRC staff regarding implementation of this recommendation for Tank 18 as soon as practical. Experiments to address this recommendation should be conducted prior to final closure of this single tank. Results of Tank 18 residual waste experiments will be evaluated by NRC staff to determine the need for additional data collection, experiments, and modeling. For Tank 18, as well as other F-Tank Farm (FTF) tanks, additional information regarding NRC staff's recommendations in this area, including details on the suggested implementation of other recommendations listed below will be provided in NRC staff's plan for monitoring the FTF later in fiscal year (FY) 2012.

As a result, NRC has identified the following monitoring factors (MFs) related to waste release:

- Solubility Limiting Phases/Limits and Validation (see Section 3.2.1)
- Chemical Transition Times and Validation (see Section 3.2.2)

Since DOE assumes the chemical transition to more soluble conditions occur for the most risk-significant HRRs in the DOE PA, both: (i) the nature of flow through the tank grout (e.g., fracture versus matrix flow) that dictates the reactive surface area and amount of grout available to condition infiltrating water, and (ii) the assumed rate of change of Eh and pH also are important to the compliance demonstration. Uncertainty related to flow through the tank grout is considered under MA 3, "Cementitious Material Performance," which is concerned with the hydraulic (rather than the chemical) performance of cementitious materials mitigating FTF releases and doses.

Other NRC technical evaluation report (TER) recommendations related to waste release are binned under PA maintenance activities under MA 6 until overall facility performance is better understood and constrained. Should the results of the experiments indicate less than favorable performance, NRC staff expects DOE to assess the impact on the results of the PA. NRC staff also will assess the need for additional experiments, data collection, and modeling to provide support for key barriers in DOE's PA that might serve to mitigate underperformance of chemical barriers. If the results of the experiments show that key radionuclides are strongly retained in the residual waste, NRC staff expects other MAs or MA components will become less important and may be closed as monitoring progresses.

Special Considerations for Tank 18

Since preparation of the FTF PA, DOE has performed additional analysis to study potential solubility of Pu in Tank 18 to support the final waste determination (WD) and near-term [calendar year (CY) 2012] closure of this tank (Denham, 2012). The analysis indicates that Pu may be present in the tank waste waters at risk-significant concentrations for what DOE describes as "conservative" or higher Eh conditions, or that Pu also can be relatively insoluble at what DOE describes as more "realistic" or lower Eh conditions. These results are important, as they show that peak doses could either be similar to those doses reported in DOE's PA (i.e., hundreds of mrem/yr) or that the peak doses from Pu could be insignificant. However, only through additional analyses and experimental validation can DOE confirm the geochemical modeling results and present a more accurate measure of risk. It also is important to note that if higher Eh conditions prevail, DOE models predict releases from the tanks much earlier in time. In Figure 3-4, a green dashed line that dissects the tank grout and contaminated zone chemical barriers[35] at around 10,000 years for Type IV tanks (including Tank 18)[36] marks the first chemical transition from reducing to oxidizing conditions, corresponding to the time at which Pu is expected to be released at risk-significant rates based on DOE's updated solubility modeling. Risk-significant release of Pu-239 at higher solubility are predicted by DOE PA models to occur much earlier in the updated solubility modeling than assumed in DOE's PA (i.e., Pu-239 was previously assumed to be released at risk-significant rates only after the second chemical transition to lower pH marked with a red dashed line after 30,000 years in Figure 3-4). If performance of the tank grout, steel liner, or basemat is slightly less than assumed in DOE's base case scenario, then release of Pu-239 into the surrounding environment could occur within the 10,000 year period of performance.

Given the risk-significance of Tank 18 to the overall FTF PA and DOE's planned near-term closure of Tank 18 in CY 2012, NRC staff recommended in its TER (NRC, 2011) that DOE initiate discussions with NRC staff regarding implementation of waste release experiments for Tank 18, as soon as practical. In its TER (NRC, 2011), NRC staff recommended experiments be conducted prior to closure of the tank. After issuance of NRC's TER (NRC, 2011), a peer review group recommended DOE update its geochemical modeling and validate modeling results with follow-up experiments (Cantrell, et al., 2011) consistent with NRC recommendations. The peer review report, however, suggested that validation experiments could occur after tank grouting had been completed. Consistent with the peer review group recommendation, DOE decided to grout the tanks and perform follow-up experiments to study waste release later in CY 2012 (SRR–CWDA–2012–00020).

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[35]Tank grout and contaminated zone chemical barriers are combined and shown in purple in Figure 3-4.
[36]Type IV tanks are illustrated in the bottom set of three panels in Figure 3-4.

Monitoring Factor 2.1—Solubility-Limiting Phases/Limits and Validation

The key radio-elements that are expected to significantly contribute to receptor dose and are sensitive to solubility limits are technetium (Tc), neptunium (Np), and plutonium (Pu). As discussed in NRC's TER (NRC, 2011), DOE models solubility limits for these elements in the DOE PA, for pure phases and, in cases of Tc and Pu, as co-precipitates with iron oxyhydroxide minerals in the residual waste. NRC staff will, therefore, emphasize these elements in monitoring how DOE treats their concentration-limited release in PA.

As mentioned above, NRC staff's primary recommendation in its TER (NRC, 2011) was that DOE conduct waste release experiments to increase support for key modeling assumptions. Accordingly, NRC will monitor experiments conducted by DOE to address the primary recommendation. With respect to the experiments, DOE should develop a plan to analyze key radionuclides that rely on solubility for control, such as Pu, Tc, and Np. The experiments should consider the effects of reagents (e.g., oxalic acid) used to remove radionuclides from the tank residue, including formation of new compounds that may alter leachability of key radionuclides. DOE should determine the number of samples to be analyzed from each waste tank based on characterization results that show the homogeneity or lack thereof of residual waste remaining in the tanks.

NRC recommends DOE perform experiments for residual waste from Tank 18 in the short-term and, based on the results of the first set of experiments and expected intertank variability, determine the need for additional experiments for remaining tanks. Decisions on additional experiments should be based on expected tank risk; HRRs targeted for these studies should be those that are the largest risk drivers and for which the reliance on chemical retention is greatest. The experiments should be representative of the final chemical and physical form of the waste (e.g., should reflect post chemical treatment for those tanks where chemical cleaning is selected as the preferred technology).

While grouting of Tank 18 has been completed, DOE should conduct tests recommended by the peer review group (Cantrell, et al., 2011) using archived samples of the tank heels or additional samples were obtained before grouting commenced. The need for this information is important, especially when considering waste reactions with water and the subsequent interactions of this leachate with soil underlying the tanks.

The remainder of this section will address, in turn, each of the three elements for which waste release is most significant to calculated dose. The Pu section exceeds the others in length mainly because recent information has become available that warranted discussion; the DOE efforts that led to much of the new information may eventually provide relevant data for Tc and Np.

Technetium

Under Oxidized Region III conditions, no solubility limit is placed on Tc in the DOE PA. Concerning Reduced Region II and Oxidized Region II, however, NRC staff still has questions regarding the applicability of the iron co-precipitation model for Tc. It appears these concerns will be moot if the tank Tc-99 inventories are reduced enough by cleaning, such that the Tc solubility limit is not risk-significant. If Tc-99 tank inventories continue to be sufficiently low, NRC staff may not need to monitor Tc solubility limit issues.

Neptunium

NRC's TER (NRC, 2011) observed that Np pure-phase solubilities used in the PA appeared reasonable. These solubility values, ranging from 1.6×10^{-9} to 1.1×10^{-4} M (SRS–REG–2007–00002, Rev. 1, Table 4.2-10), have the potential to be risk-significant if release and chemical transitions occur before 10,000 years. In addition, there are indications that DOE may employ iron co-precipitation for Np release in later PA efforts. NRC staff will, therefore, continue to monitor the Np solubility topic, including the iron co-precipitation issue and any recalculations of solubility limits using thermodynamic models.

DOE assumes the basemat is quite effective in limiting Np release in its FTF PA. Accordingly, monitoring activities concerning the Np K_ds in the basemat (Cementitious Materials Performance MA3) are discussed under MA 3, "Cementitious Materials Performance," as well as those concerned with flow through the basemat, which are discussed further under MA 5,"PA Maintenance."

Plutonium

Pu release and, therefore, dose are highly sensitive to the contamination zone solubility limit. The DOE plot seen in Figure C–1 shows that, if timing is disregarded, any Pu solubility limit above 1×10^{-10} M could yield doses that exceed the 10 CFR 61.41 compliance limit. Independent NRC staff analyses corroborate DOE's sensitivity analysis results and show that peak release rates (and therefore doses) are relatively insensitive to solubility at higher solubility levels but that, at some threshold value, tank waste solubility becomes increasingly controlling with respect to peak release and dose. Because NRC staff remains unconvinced of the timing of release, owing to uncertainty in chemical transition times and potential for tank grout bypass, a solubility limit exceeding 1×10^{-10} M, under any set of chemical conditions, has the potential to lead to an unacceptable dose within 10,000 years. Because Pu solubility limit is highly dependent on the iron co-precipitation model and on assumptions regarding any solubility limiting pure Pu phases, recommended waste release studies discussed earlier are particularly critical for Pu.

Table C–1 also shows that a Pu solubility at the source of less than 1×10^{-10} M is not likely to be risk-significant, considering minimal credit for the performance of other FTF barriers. The concentrations were calculated based on the DOE-calculated pathway dose conversion factor for Pu-239 that provides the dose to groundwater concentration ratio for this key radionuclide.

DOE convened a peer review group to assess recommendations and comments NRC made in its TER (NRC, 2011), specifically with regard to the technical justification for the assumptions and technical bases for modeling Pu release from tank residual wastes. Much of this effort focused on the solid phases of Pu in the waste and the modeling activities associated with assessing solubility of those phases. The peer review group's report points out the DOE analysis of chemistry in the tanks only provides "possible clues as to the potential nature of Pu speciation in the precipitates and residues left in the tank after extensive cleaning" (Cantrell, et al., 2011, p. 7). In addition, the report states, "There is no real understanding of the nature of Pu speciation in tank precipitates" (Cantrell, et al., 2011, p. 8). The peer review team's findings are based on several days of discussions with Savannah River Site (SRS) personnel, but presumably the peer review team was exposed to material similar to that contained in Hobbs (2012) report.

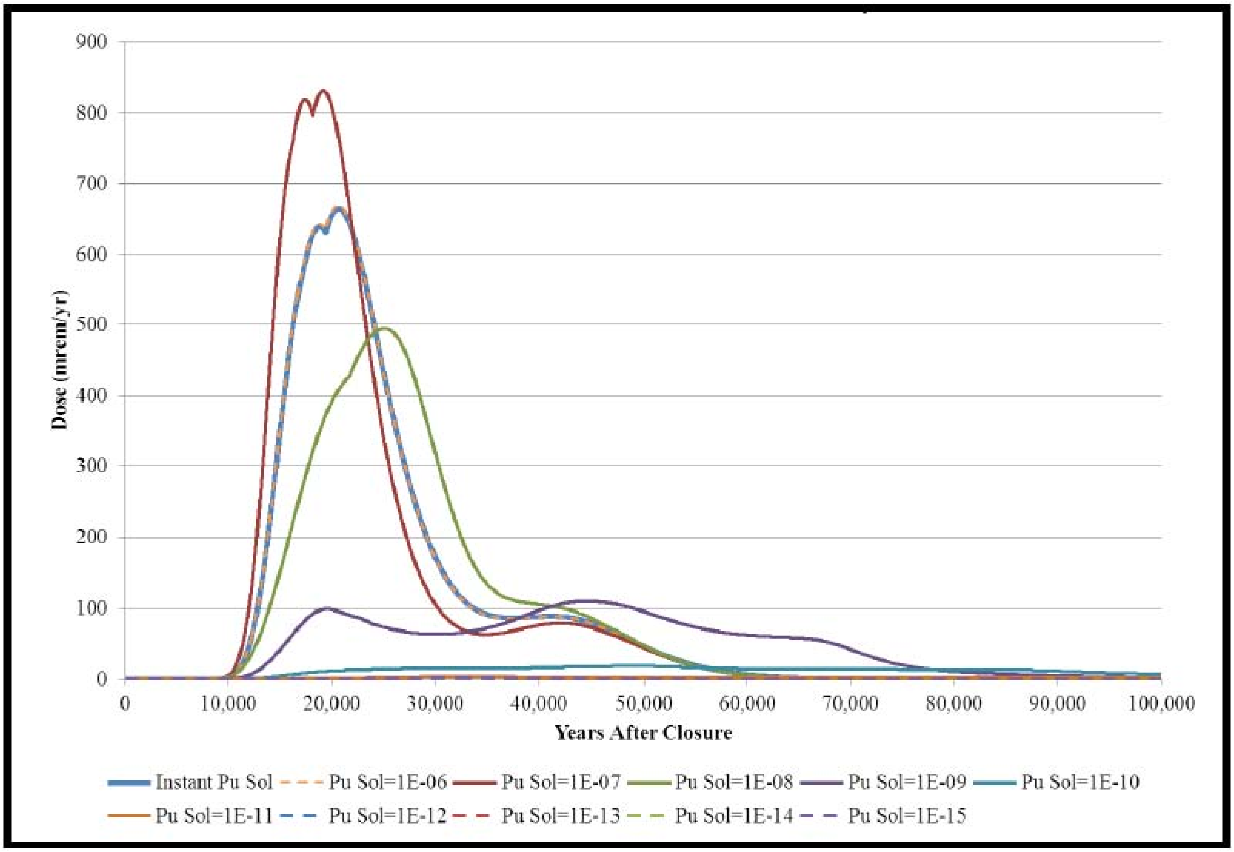

Figure C–1. Revised Tank 18/Tank 19 Special Analysis (SRR–CWDA–2010–00124, Rev. 0, Figure 6.3-23) Showing the Sensitivity of Calculated Dose to the Plutonium Solubility at the Waste Residue

Table C–1. Risk-Significant Concentrations of Pu-239 in the Environment Based on DOE F-Tank Farm Performance Assessment Modeling

	Standard	Concentration (pCi/L)	Concentration (mol/L)
Intruder	5 mSv/yr	1,100	7×10^{-11}
Member of the Public	0.25 mSv/yr	55	4×10^{-12}
Pathway Dose Conversion Factor = 4.5E-03 mSv/yr per pCi/L Specific Activity = 0.063 Ci/g 1 pCi/L = 3.7×10^{-02} Bq/pCi			

(NRC has no information on the material presented to the peer review group, beyond what is stated in its report.) The peer review team stated that, to provide a stronger scientific foundation to justify the use of geochemical modeling in the tank closure PA, validation and verification of the model and assumptions are required.

With respect to tank waste residues, the peer review group recommended:

(1) Spectroscopic analyses [e.g., Extended X-Ray Absorption Fine Structure or (EXAFS)] of Pu and other metals in the waste residues.

(2) Leach tests that use leachant solutions representative of aged as well as fresh grout and deionized water. The recommended leach tests would include the following features:

- Chemical analysis including all major ions, pH, alkalinity, Eh, and appropriate trace components (e.g., Pu, Fe, and sulfide).

- Solids characterization after leaching, because new phases may have precipitated or some phases may have dissolved completely.

- Geochemical modeling with the leachate data as input, in order to validate and verify the solubility model and certain assumptions used in the model.

In addition to these peer review group recommendations, Hobbs (2012) recommended that if the presence of $PuO(CO_3)$(am,hyd) is confirmed by X-ray absorption analysis, experiments be conducted to determine if Pu carbonates can be transformed back into PuO_2(am,hyd) upon contact with grout.

Many of the tests that were recommended by the peer review group are consistent with NRC's TER (NRC, 2011) recommendations. These tests have not been conducted yet. With this in mind, NRC staff is not confident that DOE has adequately characterized tank waste residues, especially with respect to the forms and behavior of the transuranic elements, to allow reasonable assurance that releases from the tanks have been appropriately modeled. The complex behavior of Pu and the variety of tank configurations, materials, and potential pathways for water to short-circuit closure conditions suggest DOE should conduct carefully considered leaching studies coupled to site-specific soil interaction analysis. Specifically, DOE should conduct leaching studies to ascertain maximum solubilities and leach rates of key radionuclides from the tank heels. These tests should represent different scenarios of waste-grout interactions that control factors such as pH and speciation. DOE could use leachate from the experiments to define site-specific K_ds values, based on waste-specific releases.

Hobbs (2012) provides a discussion of the possible solid phases and aqueous species in which Pu may reside in residual SRS tank wastes, based on observations of Tank 18 residues, the tank operational history, and the literature. A variety of metals, including Pu, that precipitate from solution as acidic residues from spent fuel dissolution are made alkaline by addition of NaOH. Hobbs describes three forms that the Pu may take if it co-precipitates with other, much more abundant metals, such as iron and aluminum. One potential form is Pu substitution for another metal in a crystal lattice, a second is physical occlusion into a mass of precipitated material without becoming part of the structure, and a third is adsorption onto surfaces of the material. In each of these cases, Pu would be expected to be uniformly dispersed in the solid. However, recent Scanning Electron Microscopy (SEM) analyses of a single Tank 18 waste sample (Hay, et al., 2012) show Pu present as discrete, small (<1 μm) particles that are not evenly distributed within the precipitated matrix. The Pu mass represented by these particles seems to be smaller than total Pu in the sample, suggesting that some Pu also is co-precipitated. Perhaps more importantly, the concentrations of Pu in Tank 18 waste liquids (1×10^{-8} M and 3×10^{-8} M) were "well above the predicted solubilities for PuO_2(am,hyd) and co-precipitated Pu(IV)" (less than 2×10^{-9} M) (Hobbs, 2012).

Further, Hobbs (2012) discusses how the speciation of Pu in the waste may be impacted by changes in pH and ingress of CO_2, resulting from continual active ventilation of the tanks to control hydrogen accumulation. The presence of CO_2 gas over a strongly alkaline solution will result in accumulation of carbonates in solution, inducing the formation of $PuO(CO_3)xH_2O_{(solid)}$ or

$Pu(OH)_2(CO_3)_{(solid)}$ in the presence of aqueous Pu carbonate species. In fact, carbonate concentrations of about 0.04 M were measured in the aqueous phase of Tank 18 heels. A recent X-Ray Diffraction (XRD) analysis of Tank 18 heels shows the presence of $Na_4UO_2(CO_3)_3$ and calcite at about 10 percent of the crystalline solid phase material (Hay, et al., 2012). The presence of these solids and the measured aqueous carbonate concentrations strongly suggests that some Pu in the heels is in a carbonate form. These observations have important implications for how Pu solubility is modeled, because the solubility limits for these carbonate phases could differ substantially from the hydrated Pu oxides used in DOE models. If Pu is present as a carbonate solid, then at pH 9.8, Pu solubilities of around 1×10^{-6} M can be expected (Hobbs, 2012). In addition, these observations mean that at least some of the Pu in the aqueous phase will be negatively charged carbonate complexes, which will have very low K_ds values.

In the recent special analyses for Tanks 18 and 19 (SRR–CWDA–2010–00124), DOE assumes that reaction of Pu carbonate species with the high pH of the grout will convert all Pu to the lower-solubility phases $Pu(OH)_{4(am)}$ or $PuO_{2(am,\ hyd)}$. Presumably, this would take place with free alkaline water released during grout setting or with water that percolated from the surface through the grout. In many release scenarios, water in the system will be alkaline before it contacts the waste residue. This seems reasonable for many situations. However, there are several important processes that may preclude the conditioning of water entering the contamination zone. Based on information presented in the PA, the Pu Peer Review Report, and Hobbs (2012), there are potential radionuclide release scenarios that may lead to greater leach rates than expected from the PA.

The recent analysis of one sample of tank residue by SEM and XRD has altered the conceptual model presented in the PA. From Hobbs (2012), it is reasonable to think that Pu may be present in at least three forms in the heels, and the higher than expected concentrations of aqueous Pu highlight this point. This illustrates the importance of doing a characterization of the waste, as outlined above. Other radionuclides that cannot be detected by the solid phase analytical techniques may be better characterized by the leach tests. Moreover, release rates of Pu and other related elements as well as their speciation can be used by DOE to validate modeling of this system.

In summary, DOE should characterize tank heels as recommended in NRC's TER (NRC, 2011) and by the DOE peer review group. These analyses, to be conducted on multiple samples, include: XRD; SEM/Energy Dispersive Spectroscopy (EDS); synchrotron-based studies, such as X-Ray Absorption Near Edge Structure (XANES); synchrotron microprobe; and EXAFS for selected materials. Leach tests need to be conducted under differing environmental conditions. Analyses of the leachates should attempt to determine the aqueous speciation of Pu. Tests need to be conducted to assess the ability of fluids from the grout to transform Pu carbonate solids to $Pu(OH)_{4(am)}$ or $PuO_{2(am,\ hyd)}$.

Monitoring Factor 2.2—Chemical Transition Times and Validation

DOE relies on geochemical modeling to estimate the time at which two key chemical transitions take place (i) transition from reduced to oxidized conditions reflected in an increase in Eh and (ii) transition from relatively high to relatively low pH reflected in a decrease in pH. In Section 4.2.9.3 of its TER (NRC, 2011), NRC staff discussed its concerns with the geochemical modeling results, which may be attributable to assumptions such as the solid phases that comprise the tank grout, the characteristics of the infiltrating groundwater, uncertainties in the thermodynamic data used in the modeling, or assumptions regarding the ability of grout components to react with and condition infiltrating groundwater. As illustrated in Figure C–2 (NRC, 2011, Figure 4-5), NRC staff questioned the shape of the pH vs. time curve generated, using the results of DOE's geochemical modeling. The experimental data presented in Figure C–2 suggest that DOE's conceptual model or modeling results related to chemical transition times may be flawed.

Chemical transition times also are dependent on the nature of flow through the grouted tanks. If flow is primarily through cracks, only a small fraction of the total mass of tank grout may come into contact with infiltrating water over time, thereby limiting the effective reductive and buffering capacity of the tank grout and hastening chemical transitions to higher solubility. MF 3.2—Groundwater Conditioning and MF 3.3—Shrinkage and Cracking, discussed in Sections 3.3.2 and 3.3.3 and Appendix D is concerned with the potential for preferential pathways to form that by-pass the tank grout, limit groundwater conditioning, and lead to faster chemical transition times.

For these reasons, NRC staff does not believe a compelling case has been made yet that waste release or the chemical transition to Oxidized Region II will be limited to times after the 10,000-year compliance demonstration period. For the purposes of waste release, NRC staff assumes releases and chemical transitions can occur before 10,000 years. Until DOE resolves questions of the timing of release and chemical transitions, the FTF compliance demonstration will depend on whether the highest solubility limits identified as result of monitoring activities conducted by DOE under MF 2.1 will lead to doses that meet or exceed the dose limits in 10 CFR 61.41 and 61.42.

Since preparation of DOE's PA and NRC's TER (2011), DOE has performed additional modeling (Denham, 2012) that updates the chemical transition times presented in DOE's PA. As part of this MF, NRC will review information provided in the updated solubility report as a technical review activity. However, DOE should perform experiments to validate results of the

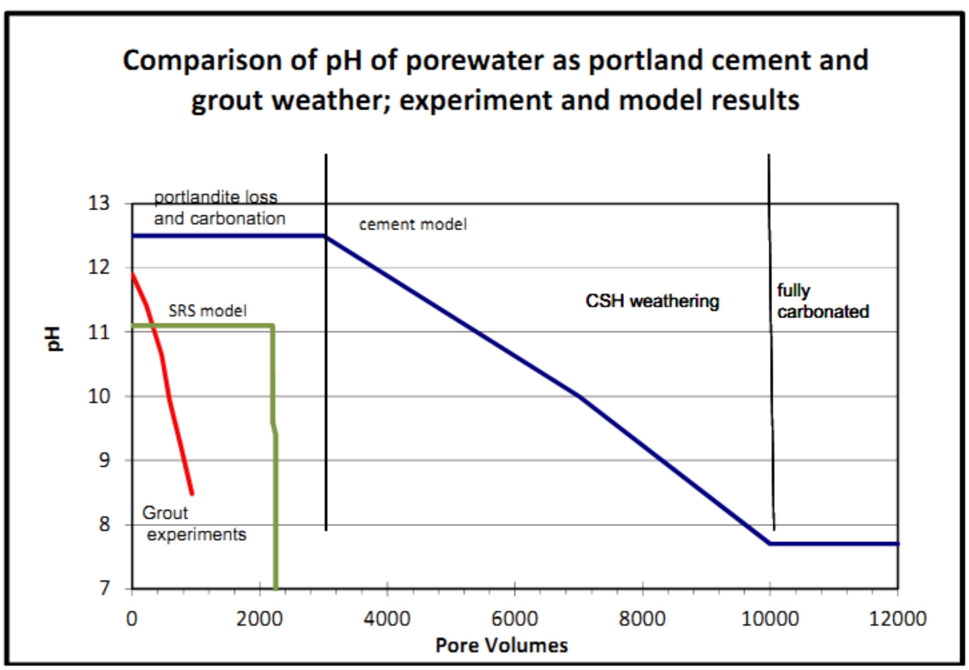

Figure C–2. Experimental Versus Modeled Change in pH Versus Displaced Pore Volumes (Dimensionless Time) (NRC, 2011, Figure 4-5; Fuhrmann and Gillow, 2009)

updated geochemical modeling. As NRC staff has expertise in design and implementation of relevant experiments, DOE should discuss with NRC staff its plans to ensure that experiments are designed to optimize their usefulness in supporting the 10 CFR 61.41 compliance demonstration. NRC staff also may observe DOE experiments related to this MF in conjunction with an onsite observation at the FTF. This MF will be closed when DOE completes experiments to study the evolution of pH and Eh in the tank grout over time to provide more accurate estimates of chemical transition times to higher solubility.

In addition to concerns regarding geochemical modeling results that show the evolution of pH and Eh over time, NRC staff also is concerned that the reducing capacity of the tank grout may not be readily transferable to the waste zone; DOE PA modeling assumes the waste zone remains in a reduced state for thousands of years (see purple barrier to the left of the green dashed line in Figure 3-4), based on conditioning from the overlying grout. NRC will, therefore, monitor the ability of FTF tank grout to maintain reducing conditions in the waste zone through experimentation or other support.

References

Cantrell, K., D.L. Clark, D.R. Janecky, J. Psaras, and W. Runde. "Plutonium Solubility Peer Review Report." LA–UR–2012–00079. Los Alamos, New Mexico: Los Alamos National Laboratory. 2011.

Fuhrmann, M. and J. Gillow. "Fate of Contaminants in Contact With West Valley Grouts." BNL–82395. Upton, New York: Brookhaven National Laboratory. 2009.

Hay, M.S., P.E. O'Rourke, and H.M. Ajo. "Summary of XRD and SEM Analysis of Tank 18 Samples." Rev. 0. Memorandum (February 23) to F.M. Pennebaker (NRC). SRNL–I3100–2012–00017. Aiken, South Carolina. Savannah River National Laboratory. 2012.

Hobbs, D.T. "Form and Aging of Plutonium in Savannah River Site Waste Tank 18, Savannah River National Laboratory." SRNL–STI–2012–00106. Aiken, South Carolina: Savannah River Nuclear Solutions, LLC. 2012.

SRR–CWDA–2010–00124, Rev. 0. "Tank 18/Tank 19 Special Analysis for the Performance Assessment for the F-Tank Farm at the Savannah River Site." Aiken, South Carolina: Savannah River Remediation, LLC. 2012.

SRS–REG–2007–00002, Rev. 1. "Performance Assessment for the F-Tank Farm at the Savannah River Site." Aiken, South Carolina: Savannah River Remediation, LLC, Closure and Waste Disposal Authority. 2010.

APPENDIX D

MA 3 "CEMENTITIOUS MATERIAL PERFORMANCE"

APPENDIX D
Monitoring Area (MA) 3 "CEMENTITIOUS MATERIAL PERFORMANCE"

The Department of Energy (DOE) relies on the cementitious materials to (i) limit the transport of corrosive species to the steel tank liner, thereby promoting the longevity of the steel liner to limit water from entering the tanks and contacting the residual waste; (ii) condition the chemistry of the water contacting the residual waste, thereby limiting dissolution of radionuclides associated with the residual waste (see MA 2 for a discussion of dissolution of residual waste); (iii) retard transport of radionuclides released from the residual waste; and (iv) stabilize waste residuals. These capabilities are directly dependent upon the hydraulic performance of the cementitious materials. The Nuclear Regulatory Commission (NRC) has identified the following monitoring factors (MFs) related to the capabilities of the cementitious materials to limit or mitigate releases from the F-Tank Farm (FTF):

- Concrete Vault Performance (As It Pertains to Steel Liner Corrosion Modeling)
- Groundwater Conditioning
- Shrinkage and Cracking
- Grout Performance
- Basemat Performance
- Use of Stabilizing Grout [As It Pertains to As Low As Is Reasonably Achievable (ALARA)]

Technical uncertainties related to the geochemical modeling performed to estimate the extent to which groundwater is conditioned by the tank grout and geochemical changes over time is addressed under MA 2 "Waste Release," MF 2.2—Chemical Transition Times. MA 3 "Cementitious Material Performance," MF 3.2—Groundwater Conditioning, focuses on the nature of flow or the hydraulic performance of the tank grout. Both monitoring factors, however, pertain to the rate at which grout degradation proceeds and leads to changes in the chemistry of the infiltrating water over time and are therefore, closely related.

Other NRC technical evaluation report (TER) recommendations related to cementitious material or steel liner[37] performance are binned by NRC under performance assessment (PA) maintenance activities under MA 6 until NRC obtains a better understanding of overall FTF facility performance. Should the results of experiments conducted under MA 2 "Waste Release" or MA 3 "Cementitious Material Performance" indicate less than favorable results, NRC staff expects DOE to assess the impact on the results of the PA. NRC staff also will assess the need for additional experiments, data collection, and modeling to provide support for key barriers in DOE's PA that might serve to mitigate underperformance of chemical and hydraulic barriers. If the results of waste release experiments show key radionuclides are strongly retained in the residual waste, NRC staff expects other MAs or MA components, including MA 3 "Cementitious Material Performance," will become less important and may be closed as monitoring progresses.

Monitoring Factor 3.1—Concrete Vault Performance (As It Pertains to Steel Liner Corrosion)

DOE relies on steel liners to limit water flow to the residual waste remaining in the tanks.

[37]Steel liner performance is indirectly related to cementitious material performance under MF 3.1—Concrete Vault Performance.

DOE's steel liner corrosion modeling relies on concrete vaults, which enclose the high-level waste (HLW) tanks, as barriers to fluid flow. DOE assumes the cementitious materials surrounding the steel liners will provide a passive chemical environment that will limit corrosion to a low general corrosion rate {1 μm/yr [0.04 mil/yr] in the base case scenario} prior to carbonation- or chloride-induced steel depassivation that can lead to higher corrosion rates. Because chemical species that induce corrosion (i.e., water, chloride, carbon dioxide, and oxygen) need to be transported through the cementitious materials, NRC staff finds that the uncertainty in steel tank liner longevity is related primarily to the hydraulic properties of the cementitious materials and their effect on the persistence of a chemical and physical environment that will limit corrosion of the steel liner.

DOE's corrosion analyses use diffusion coefficients of carbon dioxide, chloride, and oxygen applicable to intact concrete to model the transport of these species through the concrete vault. Although earlier corrosion initiation times and corrosion rates significantly higher than the general corrosion rate could result if the corrosion analyses assume higher diffusion coefficients, higher values are applied by DOE, only in limited cases in its FTF probabilistic assessment (i.e., they are not considered in the base case assessment). Also, DOE assumes concrete vault degradation starts once carbonation reaches one-half the concrete thickness, even though steel reinforcements typically have only a few inches of concrete cover. Although rebar corrosion-induced cracking of concrete would be delayed relative to carbonation of the concrete cover, initiation of concrete vault degradation may initiate sooner than assumed in DOE's concrete degradation analysis.

Additionally, although groundwater in-leakage into the concrete vaults is evident at the Savannah River Site (SRS) site, DOE does not consider this phenomenon an important factor that could influence the expected performance of the concrete vaults and steel liner. DOE projects the steel liners for 18 of 22 tanks fail after 10,000 years in the FTF PA reference case. The steel liners of four Type IV tanks are projected by DOE to fail in the DOE PA after 3,600 years and, thus, these tanks also provide a rather significant barrier to waste release. Because Type IV tank bottoms are near the water table, NRC staff also is concerned that intermittent flooding of the tank bottoms due to water table fluctuations over the long period of performance could (i) expose the tank liners periodically to corrosive environments and (ii) cause contaminants exiting the basemat to be released directly into the saturated zone. For example, DOE corrosion analyses conducted to support the H-Tank Farm (HTF) PA (SRR–CWDA–2010–00128, Rev. 0) indicate that corrosion could be significantly enhanced if the tanks are exposed to groundwater. These analyses indicate the median time to failure for HTF Type I tanks decreases to 4,183 years in the presence of groundwater from 7,630 years in soils with no significant groundwater, and the median time to failure of HTF Type II tank decreases to 4,890 years in the presence of groundwater from 13,600 years in soils with no significant groundwater. Also in the HTF PA, the contaminant flux leaving submerged or partially submerged waste tanks pass directly into the saturated zone. Given the risk significant barrier to waste release provided by the SRS FTF Type IV tanks, DOE should evaluate the potential effect of exposure of Type IV tanks to water table fluctuations on waste release. Amidon, et al. (2012) also notes that given the close proximity of Type I tanks to the water table, the likelihood that groundwater could come in contact with the grouted tanks is high since the average depth to water ranges from 0.3 to 2 m [1 to 6 ft].

Given the risk significance of the steel liner barrier, DOE should provide additional support for the assumptions used in its base case assessment that concrete vaults will remain an effective fluid flow barrier that prevents exposure of the tanks to corrosive conditions for thousands to tens of thousands of years. A peer review panel that evaluated the DOE PA modeling of waste release and transport noted that fracturing of the cement-based material with preferential flow through cracks would appear to be a more likely scenario that should be evaluated (Cantrell, et al., 2012). While referring to the waste release model, this statement by the peer review panel also applies to cementitious material degradation, suggesting that slow carbonation of cement-based material by diffusion of carbon dioxide seems like a low probability scenario.

NRC staff will review reports, analog studies, and other information used to support DOE's assumption regarding initial conditions and performance of the concrete vaults. For example, NRC staff will review annual tank inspection reports that provide information regarding trenching, scarifying, and cracking of the concrete vaults, as well as information about groundwater intrusion into the tank vaults. NRC staff will review reports related to previous events that led to potential releases for groundwater in-leakage through joints or cracks in the concrete vaults. Analog studies could include review and evaluation of information obtained from West Valley or other analog sites to better understand the potential for and rates of corrosion of HLW tanks/components, as well as mitigative design measures. As part of this MF, NRC staff also will consider the potential for earlier steel liner failure than assumed in DOE's PA due to corrosion of steel components (e.g., rebar) in the concrete vaults that are close to the vault surface.

If DOE performs additional modeling or experiments to study the potential for transport of deleterious species into the tank vaults and subsequent corrosion of the steel liners or tanks, NRC staff will review the documentation or provide input on the design and results of the experiments. Experiments to study steel liner corrosion are expected to be relatively difficult to implement with unknown benefit compared to other experimental investigations recommended in NRC's TER (2011) and discussed in this monitoring plan. Therefore, these experiments are not considered a high priority by NRC staff at this time. NRC staff will assume the steel liners will not be effective at mitigating releases for the long periods of time relied on for performance in the FTF PA and will investigate the support for the performance of other barriers to ensure that the performance objectives (POs) can be met. Should results of other investigations indicate that FTF barriers relied on in DOE's reference (or best-estimate) PA case are not expected to perform as well as assumed, then more thought will be given to methods for obtaining additional support for steel liner performance assumptions, including use of a patch model that could simulate such processes as partial failure and slower release rates from the tanks.

NRC staff may conduct technical review activities listed above in conjunction with onsite observations that could help inform its assessment of the concrete vaults as a hydraulic barrier mitigating steel liner corrosion. If DOE conducts experiments to provide additional support for concrete vaults as effective hydraulic barriers, NRC staff may observe these experiments at SRS facilities.

Monitoring Factor 3.2—Groundwater Conditioning

The hydraulic performance of the tank grout is important to DOE's compliance demonstration because it both limits infiltration and delays chemical transition times to higher solubility, thereby reducing and delaying waste release from the contaminated zone for long periods of time. The transitions in chemical conditions in the grout and residual waste that generally lead to higher solubility are directly dependent on how water flows through the grouted tanks and, potentially, from below the tanks. NRC staff has unresolved technical concerns regarding the potential for the existence or creation of fast flow paths through the grouted tanks. The potential for relatively rapid chemical modifications along these flow paths, and consequent chemical transitions, have not been ruled out. For example, water may flow along cracks relatively rapidly and react with the grout lining the crack walls. This may lead to a chemical environment for percolating water that is quite different from that for water permeating through the bulk grout (e.g., lower pH, higher Eh, and higher aqueous carbonate—as a result of calcification of the crack walls). Furthermore, DOE has not provided information to rule out the potential for water table rise to the level of the tank bottoms in the future. This scenario could afford contact with the residual waste at the tank bottom with limited benefit of the buffering grout that lies above the residue.

NRC staff is particularly concerned with DOE's PA assumptions regarding the transition from reduced to oxidized conditions. For example, it is not clear to NRC staff that infiltrating groundwater will, in fact, be conditioned to low Eh by the tank grout. The Center for Nuclear Waste Regulatory Analyses (CNWRA®) has collected experimental data relevant to the saltstone disposal facility under contract with NRC. This data indicates that even if a significant portion of the system remains in a reduced state, minimal interaction between infiltrating groundwater and the reduced inner pore space of the waste form may occur, such that the Eh of the groundwater is more reflective of the incoming groundwater chemistry, rather than a groundwater conditioned by the waste form grout (Pabalan, et. al., 2012). Because flow rates used in CNWRA experiments are higher than might occur in the real system, it is possible that the experimental conditions might not be representative of the real system. Therefore, DOE should undertake experiments using grout formulations consistent with those used or planned for FTF tanks to confirm PA assumptions regarding groundwater conditioning and chemical transition times that are important to FTF compliance demonstration. NRC staff also will evaluate the efficacy of using data from lysimeter studies at SRS planned for fiscal year (FY) 2012 to corroborate PA assumptions regarding groundwater conditioning for FTF. For example, the extent to which infiltrating water is conditioned by saltstone waste form present in the lysimeters may be used to support assumptions regarding conditioning of infiltrating water by FTF tank grout.

For several tanks with bottoms located near the water table, including Tanks 18 and 19, groundwater from a rising aquifer (about pH 5.5) could intrude through corroded liners and contact waste along the bottom of the tank. This scenario is similar to Configuration E in DOE's PA (SRS–REG–2007–00002, Rev. 1, p. 595). However, DOE did not consider the possibility of essentially unconditioned groundwater contacting the waste after passing through the corroded liner. It is interesting to note that in the HTF PA, DOE did consider such an unconditioned release scenario for tanks in a similar configuration (SRR–CWDA–2010–00128, Rev. 0). The lack of characterization of the waste, and especially the transuranic elements in it, will have substantial impact on the uncertainties presented by a water table rise scenario. NRC staff will evaluate the likelihood of this scenario under this monitoring factor through review of historical water table data.

Another DOE FTF PA scenario is characterized by preferential pathways through the grout, along either cracks or shrinkage voids along the tank margins. In reality, carbonation of the grout can be expected to be relatively rapid along the preferential pathways. These calcite/aragonite coatings may inhibit conditioning of ingress water by the grout, such that the pH of the water is more likely conditioned by calcite rather than the grout hydroxide. In addition, the reducing capacity of the grout could decline relatively rapidly along these preferential pathways. DOE evaluated the performance impact of preferential pathways in Cases C, D, and G. Case G, developed in response to NRC requests for information (RAIs), also addressed other potential issues with DOE's base case analysis. In all cases, peak doses were in the range of a few mSv/yr (100s of mrem/yr) from Pu-239 (SRS–REG–2007–00002, Rev. 1; SRR–

CWDA–2009–00054, Rev. 1). The primary difference between these cases was the timing of the peak dose. Because Case G also considered an earlier transition to higher solubility limiting phases, this scenario resulted in peak doses that exceeded the dose standard in 10 CFR 61.41 within 10,000 years. Therefore, if Case G is found to be more likely than assumed by DOE, the extent to which groundwater is conditioned under this scenario may become important to the compliance demonstration and will be evaluated under this monitoring factor.

Monitoring Factor 3.3—Shrinkage and Cracking

As discussed in the preceding section, the hydraulic performance of the tank grout is important to DOE's compliance demonstration because it both limits infiltration and delays chemical transition times to higher solubility chemical conditions, thereby reducing and delaying waste release from the contaminated zone for long periods of time. In the DOE PA model, the longevity of the chemical-barrier performance within Type IV tanks is greater than tanks in Types I or III/IIIA due to a combination of factors, including the (i) larger grout volume in Type IV tanks, (ii) lower hydraulic conductivity of Type IV tank grout for longer periods of time due to the absence of cooling coils that may fail the tank grout earlier due to corrosion-induced cracking, and (iii) shedding of water around the Type IV tanks due to a domed roof. But also an important factor in the longevity of the chemical-barrier performance within Type IV tanks is the DOE assumption that the infiltrate reaching the contaminated zone does not bypass the waste tank grout (via fast flow pathways). Instead, downward flow through the grout remains relatively uniform and significant across the plane of the contaminated surface. DOE should provide additional support for this assumption. NRC staff is concerned that in actual field conditions, only a fraction of the grout components may be accessible for reaction with the infiltrate, particularly if flow occurs through preferential fast pathways. Preferential fast flow pathways could include shrinkage gaps that form:

- Between the Tank Grout and Steel Liner
- Between the Gank Grout and Internal Fixtures
- At Lift Interfaces
- In Between Individual Grout Flow Lobes, Including the Pseudo-Cracks Formed at Internal Fixtures Where Grout Split by an Obstacle Into Two Lobes Merges Gack Together to Form a Vertical Seam on the Trailing Edge of the Obstacle

CNWRA observed many of the features listed above through an independent, NRC-funded study of large grout monoliths (Walter and Dinwiddie, 2008; Walter, et al., 2009, 2010; Dinwiddie, et al., 2011; Dinwiddie, et al., 2012). The study is providing information to help assess the robustness of DOE assumptions regarding the nature of flow through the tank grout that affects the calculated chemical transition times. NRC conducts these analyses to independently inform its review rather than make conclusive findings because NRC recognizes these studies cannot fully duplicate conditions in waste tanks at SRS. DOE should consider conducting its own grout studies and inspections of the distribution, consistency, flowability, and topography of the grout, as it is placed in the tanks, as well as measurement of the in-place physical properties of the grout, including vertical distribution and temporal evolution of grout density, porosity, and permeability. These activities could provide the information necessary to support key FTF PA modeling assumptions.

DOE also should consider design measures to minimize the occurrence of negative features, events, or processes related to grout placement. For example, DOE should consider removal of in-tank equipment that could lead to development of shrinkage-induced annuli around equipment or corrosion of steel components and associated cracking due to corrosion product expansion. DOE also should ensure the ability of the tank grout to fill all void spaces (i.e., grout should be self-leveling) to minimize imperfectly bonded grout seams and voids that may form in between grout pours. DOE should research and evaluate shrinkage compensating agents for use in its grout formulations to minimize shrinkage, shrinkage gap formation, and creation of annuli and void space within the tank grout, as recommended in Stefanko and Langton (2011).

Preferential fast flow pathways also include cracks that form due to thermal or mechanical stresses (e.g., those due to settlement or corrosion product expansion from steel component corrosion). NRC will request information regarding thermal gradients generated during tank grout curing and evaluate potential for thermal cracking in a future technical review activity or onsite observation. Cracking due to settlement is discussed in Section 6.2.

NRC staff also is concerned with potential formation of cracks in the tank grout due to alkali silica reaction (ASR). ASR is a process whereby reactive aggregates breakdown under exposure to the highly alkaline pore solution in concrete, which can result in significant expansion and, in some cases, cause cracking of concrete. This concern arose because the grout being used to fill Tanks 18 and 19 include 3/8-inch granite “pea gravel” as aggregates, instead of using only sand aggregate, as described in the DOE PA document (SRS–REG–2007–00002, Rev. 1), and because of recent observations of concrete cracking at the Seabrook Nuclear Power Plant in Seabrook, New Hampshire. In that facility, granite aggregates also were used in the concrete mix. ASR is a slow process and its occurrence at Seabrook became evident only decades after the plant was constructed. Grout fill mix in Tanks 18 and 19 contain less Portland cement than the concrete mix used at Seabrook and likely would be less susceptible to ASR. Nevertheless, NRC staff is concerned that DOE’s criterion for acceptance of vendor supplied granite aggregate relies on short-term alkali reactivity tests (ASTM C–1260), which is unlikely to predict the occurrence of ASR over the very long period of performance for compliance with PO 61.41. NRC staff will discuss this issue with DOE and evaluate the potential for ASR to negatively impact FTF performance in a future technical review activity or onsite observation.

NRC staff will review grout formulations, calculations, research, test methods, and results to ensure the disposal facility is designed to minimize fast flow path development. NRC staff may conduct technical reviews in conjunction with onsite observations that could include such activities as video inspections of grout pours, observations of grout tests, and inspections of test specimens.

Monitoring Factor 3.4—Grout Performance

During onsite observations, NRC staff will verify the actual grout formulation DOE uses is consistent with performance assumptions in the FTF PA (SRS–REG–2007–00002, Rev. 1) and design specifications assumed in the final waste determination (WD) (DOE/SRS–WD–2012–001). DOE should evaluate significant deviations from the design specifications to ensure expected grout performance will not be negatively affected. In addition, NRC staff will evaluate DOE’s program for sampling, testing, and accepting grout materials to ensure materials conform to DOE specifications and national standards, such as ASTM C–989. The verification program should incorporate a comprehensive record-keeping system to include, for example (i) plant operation records, (ii) vendor-provided test reports on the grout components, (iii) as-received acceptance test reports on bleed, slump, and/or flow of each grout batch (e.g., ASTM C–232, ASTM C–143, ASTM C–1611) and records of any additional water or other components added onsite to meet the acceptance criterion prior to emplacement, (iv) DOE laboratory test results of composite or grab samples, and (v) certification of shipping records.

Also, NRC staff will evaluate the adequacy of the verification program pertaining to DOE's supply of grout components, such as blast furnace slag. NRC staff's evaluation will be based, to the extent practicable, on direct observation of ongoing activities and interviews with key DOE personnel. The review will evaluate certain aspects of the program:

- Representativeness of the Samples Collected
- Adequacy of the Analytical Equipment
- Calibration of the Analytical Equipment
- Adequacy of Verification Records

To minimize degradation in the quality and chemical reactivity of the slag and Portland cement, DOE must store the material in weather-tight silos or bins to prevent contact with moisture. During onsite observations, NRC staff will examine silos or bins for storage of the slag and cementitious materials. In addition to the grout formulation, curing conditions also are expected to have a significant effect on the short- and long-term performance of the emplaced grout. Numerous studies have shown that improper curing results in a variety of undesirable effects, such as lower strength, high permeability, and several types of cracking. For example, early age cracking could occur due to thermal and self-dessication stresses and uneven lift topography. DOE streamed live video (over the internet) of the initial grout pours into Tank 18, which provided important information regarding grout flowability and non-self-leveling grout behavior. The technology needed to observe most stages of grout emplacement has thus been proven and DOE should continue to use this technology during grout emplacement. NRC will review video footage of grout emplacement activities to (i) provide confidence that grout behavior during emplacement is understood and (ii) incorporate this information into NRC reviews of PA updates. Staff performing onsite observations will verify grout placement is conducted under proper temperature and humidity conditions or that steps are taken to ensure proper curing of the grout.

Monitoring Factor 3.5—Basemat Performance

An additional NRC concern pertains to the hydraulic and chemical performance of the FTF concrete basemat, which NRC considers an important barrier to radionuclide release. Despite the relatively short transport pathway, sorption onto the concrete basemat attenuates release of highly radioactive radionuclides (HRRs), such as Np and Pu, by orders of magnitude in DOE's PA. DOE barrier analyses indicate the presence of a fast flow path through the basemat causes a more rapid release of contaminants. This effect is more evident for Pu because of its high sorption coefficient in oxidized concrete. Notwithstanding results of the barrier analyses, a fast flow path through the basemat is not considered a likely scenario in the DOE PA base case. DOE needs to provide support for its base case assumption that the basemat will remain intact. In particular, the basemat underneath Type IV tanks is only 10 cm [4 in] thick and could be susceptible to cracking due to stress imposed by the mass of emplaced grout.

References

Amidon, M.B., et al. "Alternative Risk Reduction Technologies in Support of F-Tank Farm Closure." SRNL–STI–2012–00079. Aiken, South Carolina: Savannah River Site. 2012.
Cantrell, K., D.L. Clark, D.R. Janecky, J. Psaras, and W. Runde. "Plutonium Solubility Peer Review Report." LA–UR–2012–00079. Los Alamos, New Mexico: Los Alamos National Laboratory. 2011.

Denham, M. "Evolution of Chemical Conditions and Estimated Plutonium Solubility in the Residual Waste Layer During Post-Closure Aging of Tank 18, Savannah River National Laboratory." SRNL–STI–2012–00087. Aiken, South Carolina: Savannah River Nuclear Solutions, LLC. 2012.

Dinwiddie, C.L., D.R. Bannon, M.K. Todt, G.R. Walter, and M.M. Roberts. "Draft Fiscal Year 2012 Meso- and Intermediate-Scale Grout Monolith Test Bed Experiments: Results and Recommendations." San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses. 2012.

Dinwiddie, C.L., G.R. Walter, G. Light, S. Winterberg, D. Wyrick, D. Sims, and K. Smart. "Bonding and Cracking Behavior and Related Properties of Cementitious Grout in an Intermediate-Scale Grout Monolith." San Antonio, Texas: Center for Nuclear Waste Regulatory Analysis. 2011.

Pabalan, R.T., G.W. Alexander, and D.J. Waiting. "Experimental Study of Contaminant Release From Reducing Grout." San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses. 2012.

SRR–CWDA–2009–00054, Rev. 1. "Comment Response Matrix for Nuclear Regulatory Commission (NRC) Comments on the Draft Basis for Section 3116 Determination and Associated Performance Assessment for the F-Tank at the Savannah River Site." Aiken, South Carolina: Savannah River Remediation, LLC, Closure and Waste Disposal Authority. 2011.

SRR-CWDA-2012-00020, Rev. 0. "Savannah River Site Liquid Waste Facilities Performance Assessment Maintenance Program, FY2012 Implementation Plan," Aiken, South Carolina: Savannah River Remediation, LLC. 2012.

SRS–REG–2007–00002, Rev. 1. "Performance Assessment for the F-Tank Farm at the Savannah River Site." Aiken, South Carolina: Savannah River Remediation, LLC, Closure and Waste Disposal Authority. 2010.

Stefanko, D.B. and C.A. Langton. "Tanks 18 and 19-F Structural Flowable Grout Fill Material Evaluation and Recommendations." SRNL–STI–2011–00551. Rev. 0. Aiken, South Carolina: Savannah River National Laboratory. 2011.

U.S. Army Corps of Engineers. "Geologic Engineering Investigations." Vicksburg, Mississippi: Waterways Experiment Station, U.S. Army Corps of Engineers. 1952.

Walter, G.R., C.L. Dinwiddie, D. Bannon, G. Frels, and G. Bird. “Intermediate Scale Grout Monolith and Additional Mesoscale Grout Monolith Experiments: Results and Recommendations. San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses. 2010.

Walter, G.R., C.L. Dinwiddie, E.J. Beverly, D. Bannon, D. Waiting, and G. Bird. “Mesoscale Grout Monolith Experiments: Results and Recommendations.” San Antonio, Texas: Center for Nuclear Regulatory Analyses. 2009.

Walter, G.R. and C.L. Dinwiddie. “Conceptual Design for Small-Scale Grout Monolith Tests.” San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses. 2008.

APPENDIX E

MA 4 “NATURAL SYSTEM PERFORMANCE”

APPENDIX E
Monitoring Area (MA) 4 "NATURAL SYSTEM PERFORMANCE"

Monitoring Factor 4.1—Natural Attenuation of Pu

The choice of appropriate distribution coefficient (K_ds) values for radionuclides in the natural system is very important to performance assessment (PA) analyses and has been the subject of considerable effort at Savannah River Site (SRS). Sorption of Pu and other key radionuclides on the natural materials of the saturated zone is especially important for Type IV tanks, such as 18 and 19, because of the very thin (or nonexistent) unsaturated zone underlying these tanks. As radionuclides are leached from the waste and released to the soil, K_ds will be a critical barrier that will depend on a number of factors including pH, ionic strength of the solution, speciation of the radionuclides and their oxidation state(s).

In the F-Tank Farm (FTF) PA (SRS–REG–2007–00002, Rev. 1), Pu is one of the most important radionuclides contributing to peak dose. For oxidized forms of Pu (V/VI) the "best" value for K_ds is 16 mL/g. For reduced forms of Pu (III/IV) the "best" value for K_ds is 300. Because Pu can exist in several redox states at the same time, a "combination" "best" value was suggested as 290 mL/g. These values were taken from Kaplan (2010) as the "best" estimates for sandy sediment. As explained in the report, the combination value is a hybrid that is taken to describe fractions of Pu in two different oxidation states: 95 percent of reduced Pu (III/IV) and 10 percent oxidized (V/VI) [sic].

Subsequent to preparation of the Department of Energy's (DOE's) FTF PA (SRS–REG–2007–00002, Rev. 1), Section 6.3.5.3.4 of the Tanks 18 and 19 Special Analyses (SRR–CWDA–2010–00124, Rev. 0) explains that Pu K_ds values were reevaluated. Section 6.3.6.1 of the special analyses (SRR–CWDA–2010–00124, Rev. 0) considers the impact of the new K_ds values on the deterministic model results. A statistical analysis of 65 K_ds values (Almond et al, 2012) taken from many areas and materials around the SRS, was conducted in an attempt to reexamine K_ds from a site-wide perspective. Almond (2012) only grossly considers chemistry in evaluating K_ds for FTF (e.g., pH is binned into two categories; greater or less than 7 and Pu redox state is not considered). Almond (2012) recommends a K_ds value of 650 L/kg for FTF based on the following: (i) information from a modeling analysis (Demirkanli et al., 2007) of long-term lysimeter studies (Kaplan et al, 2006) indicates that a K_ds of 1800 L/kg should be used, and that (ii) the statistical analysis shows that the 290 L/kg value used in the FTF PA is in the lower quantile. The sediment in the lysimeter appears to have had more clay in it than typically found at FTF and so, the 1800 value was lowered to 650 L/kg. This value, in turn, was increased for the "near field" of the tanks, using a factor of two recommended in Kaplan (2010) to account for greater adsorption due to elevated pH resulting from grout component leaching.

The work to analyze and model results of the SRS Pu lysimeters has led to a model in which a reduction rate and an oxidation rate drive concentrations of different Pu redox states at any given time (Kaplan, 2010; Kaplan, et al., 2006; Demirkanli, et al., 2007). This leads to a small fraction of mobile Pu and a large fraction of relatively recalcitrant Pu. To reproduce the profiles in the lysimeters, the two rates and the retardation factor needed to be adjusted. In lysimeters containing reduced Pu sources, a retardation factor of 15 was used for Pu in the small, mobile fraction, while a retardation factor of 10,000 was used for the larger fraction. Even with the high retardation of the large fraction, modeling was not able to capture the overall Pu distribution in the lysimeter by using a single species retardation factor (Demirkanli, et al., 2007). The small, mobile fraction caused the soil profile of Pu below the source.

The long-term lysimeter experiments conducted at SRS and other work referenced in Kaplan (2006) show that although most Pu is in the (IV) state, there is a small component, that at times, is in a much more mobile form. In fact, most Pu that is in solution (albeit a very small concentration) is in the Pu (V) form. Even PuO_2(s), which had been considered a stable form of Pu (IV), has been shown to oxidize in the presence of water forming a substantial fraction (27 percent) of Pu (VI) (Haschke, et al., 2000). In SRS sediment, it is thought that Pu cycles repeatedly through the Pu (IV) and Pu (V) oxidation states in response to wet/dry cycles (Kaplan, 2003)

From Kaplan (2010) the "best" K_ds value for sandy soil for Pu (V/VI) is 16 mL/g, while for Pu (III/IV) the "best" value is 300 L/kg. Recognizing that Pu chemistry is especially complex and disproportionation presents a difficult problem; NRC staff suggests that averaging K_ds values for different oxidation states is not appropriate, even if values are weighted for proportions of different redox states.

A potential additional complication is the possibility that Pu (III) can be produced by certain common Fe (II) species, and that the Pu (III) form can be more soluble or mobile than Pu (IV). The finding by Felmy, et al. (2011) that Pu (IV) can be reduced to Pu (III) by Fe (II) and that the presence of certain Fe (III) minerals increases the reaction rate, suggests that for long-times a single K_ds, steady-state adsorption model may not be appropriate. For the SRS lysimeters containing sources of reduced Pu, X-Ray absorption near edge structures (XANES) showed that in the soil, Pu was distributed approximately 37 percent Pu (III), 67 percent Pu (IV) 0 percent Pu (V), and 0 percent Pu (VI) (Kaplan, et al., 2007). This distribution was essentially the same for both the Pu (III) and Pu (IV) lysimeters. In both cases, most Pu remained very close to the source over 11 years; however, a small but measurable quantity of Pu in the sediment had migrated to a maximum of 15 cm from the source, giving a concentration of about 1 pCi/g. XANES is not sensitive to species that are less than about 5 percent abundance, so even if some Pu (V) were present, it would almost certainly not be observed. From the evidence based on research at SRS, it is apparent that in the presence of reduced Pu, some small fraction can be oxidized, enter solution, and become relatively mobile. This is probably an ephemeral process, with Pu (IV) and Pu (V) switching back and forth, but always heavily dominated by Pu (IV). Factors such as complexation of the aqueous phase and possibly microbiological activity will potentially influence this distribution in a currently unknown way.

The use of a factor to adjust K_ds for effects of higher pH due to grout is an arbitrary adjustment that will vary with pH, time, and aqueous speciation. It also depends on the scenario by which water intrudes into the tanks, with some conceptual models not involving water that has been conditioned by grout. While leachate that is influenced by cement chemistry is expected to have an impact on vadose zone K_ds, as discussed in NRC's comments on DOE's Rev. 0 PA (comment FF-2) and DOE's Rev. 1 PA (comment RAI-FF-4) (see [NRC, 2010]), the basis for what appears to be an arbitrary increase in the K_ds is not clear. NRC staff's evaluation of DOE's updated K_ds will be the subject of a future NRC technical review memorandum under this monitoring factor.

Hobbs (2012) provides a discussion of the possible solid phases and aqueous species in which Pu may reside in residual tank wastes. Recent scanning electron microscopy (SEM) analysis (of a single waste sample) is reported (Hay et al., 2012) to show Pu present as discrete, small (<1 um) particles that are currently not characterized. The mass of these particles seems to be smaller than total Pu in the sample, suggesting that some Pu also is coprecipitated. Further the formation of $PuO(CO_3)xH_2O_{(solid)}$ or $Pu(OH)_2(CO_3)_{(solid)}$ in the presence of aqueous Pu carbonate species in the tank heels is viewed as a likely possibility. In fact, carbonate concentrations of about 0.04 M were measured in the aqueous phase of Tank 18 heels. Recently, X-Ray diffraction (XRD) analysis of Tank 18 heels shows the presence of $Na_4UO_2(CO_3)_3$ and calcite at about 10 percent of the crystalline solid phase material (Hay, et al., 2012). The presence of these solids and the measured aqueous carbonate concentrations strongly suggests that some Pu in the heels is in a carbonate form. If Pu is present as a carbonate solid, then at pH 9.8, relatively high Pu solubilities of around 1×10^{-6} mol/L can be expected. Hobbs suggests that the OH^- from the grout, in contact with the heels, should convert the carbonate to less soluble $Pu(OH)_{4(am)}$ or $PuO_{2(am,\ hyd)}$. However, it is not clear if this process does in fact take place; Hobbs recommends experiments to verify the transformation. These observations suggest that at least some of the Pu in the aqueous phase in the heels will be negatively charged carbonate complexes of higher solubility. Hobbs (2012) reported that $Pu(OH)_2(CO_3)_2^{-2}$ was the dominant solution Pu species between pH 9.4 and 10.1, while $Pu(OH_4)(CO_3)_2^{-4}$ was the dominant Pu solution species when pH was between 12 and 13. If these species are present in leachate from the grouted tanks, then very low K_ds values can be expected. The stability of these species under high pH and varying redox conditions is not clear.

Therefore, based on the information presented above, NRC staff will monitor DOE's efforts to conduct transport modeling that explicitly accounts for the multiple oxidation states of Pu that may be present or may form during transport through the FTF far-field. K_ds for Pu should be developed based on sorption studies relevant to FTF (i.e., based on sorption to sediments encountered during transport from the FTF tanks to various points of compliance and considering important changes to geochemical conditions that may occur over space and time).

References

Demirkanli, D.I.,F.J. Molz, D.I. Kaplan, R.A. Fjeld, and S.M. Serkiz. "Modeling Long-Term Plutonium Transport in the Savannah River Site Vadose Zone." *Vadose Zone Journal*. Vol.6. pp. 344–353. 2007.

Felmy, A., D.A. Moore, K.M. Rosso, O. Qafoku, D. Rai, E.C. Bock, and E.S. Ilton. "Heterogenous Reduction of PuO_2 With Fe(II): Importance of the Fe(III) Reaction Product." *Environmental Science and Technology*. Vol. 45. pp. 3,952–3,958. 2011.

Haschke, J.M., T.H. Allen, and L.A. Morales. "Reaction of Plutonium Dioxide With Water: Formation and Properties of PuO_{2+x}." *Science*. Vol. 287. pp. 285–287. 2000.

Hay, M.S., P.E. O'Rourke, and H.M. Ajo. "Summary of XRD and SEM Analysis of Tank 18 Samples." Rev. 0. Memorandum (February 23) to F.M. Pennebaker (NRC). SRNL–I3100–2012–00017. Aiken, South Carolina. Savannah River National Laboratory. 2012.

Hobbs, D.T. "Form and Aging of Plutonium in Savannah River Site Waste Tank 18, Savannah River National Laboratory." SRNL–STI–2012–00106. Aiken, South Carolina: Savannah River Nuclear Solutions, LLC. 2012.

Kaplan, D.I. "Geochemical Data Package for Performance Assessment Calculations Related to the Savannah River Site." SRNL–STI–2009–00473. Aiken, South Carolina: Savannah River Site. 2010.

Kaplan,D.I., B.A. Powell, M.C. Duff, D.I. Demirkanli, M. Denham, R.A. Fjeld, and F.J. Molz. "Influence of Sources on Plutonium Mobility and Oxidation State Transformations in Vadose Zone Sediments." *Environmental Science and Technology*. Vol. 41, No. 21. pp. 7,417–7,423. 2007.

Kaplan, D.I., I. Deniz, D.I. Demirkanli, L. Gumapas, B.A. Powell, R.A. Fjeld, F.J. Molz, and S.M. Serkiz. "Eleven Year Field Study of Pu Migration From Pu III, IV, and VI Sources." *Environmental Science and Technology*. Vol. 40, No. 2. pp. 443–448. 2006.

Kaplan,D.I. "Enhanced Plutonium Mobility During Long-Term Transport Through an Unsaturated Subsurface Environment." WSRC–MS–2003–00889. Aiken, South Carolina: Savannah River Site. 2003.

NRC. "U.S. Nuclear Regulatory Commission Staff Requests for Additional Information on the Draft Basis for Section 3116 Determination for Closure of F-Tank Farm at the Savannah River Site (Rev. 0) and on Performance Assessment for the F-Tank Farm for the Savannah River Site (Rev. 1)." DOE/SRS–WD–2010–001. Memorandum from L. Camper (NRC) to F. Marcinowski (DOE). ML103190402. Washington, DC: U.S. Nuclear Regulatory Commission. 2010.

SRS–REG–2007–00002, Rev. 1. "Performance Assessment for the F-Tank Farm at the Savannah River Site." Aiken, South Carolina: Savannah River Remediation, LLC, Closure and Waste Disposal Authority. 2010.