NRC Staff Comments on the “Performance Assessment for the F-Tank Farm at the Savannah River Site”

Inventory Comments

In the “Performance Assessment for the F-Tank Farm at the Savannah River Site,” (WSRC, 2008) (hereafter referred to as “the PA”), DOE provides inventory estimates for residual wastes remaining in tanks and ancillary equipment for use in the PA calculations. Inventory estimates are risk-significant because inventory is directly related to peak dose for those radionuclides that are not solubility limited. The following comments address: (1) potential issues associated with the screening process used to select key radionuclides; (2) estimates of radionuclide inventories for those tanks that have been cleaned and sampled and; (3) the need for additional support for inventory estimates for those tanks that have yet to be cleaned.

To develop the following comments, staff reviewed the PA and supporting documents provided to NRC by letter dated August 20, 2008 (Spears, 2008). The staff’s review criteria pertaining to radionuclide inventory in residual waste are contained in sections 3.1, 3.2, 4.2, 4.3.3, and 4.4 of NUREG-1854, “NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations” (NRC, 2007).

Comment IN-1

In the PA, the list of key radionuclides for groundwater all-pathways is determined based on drinking water dose alone. This drinking water dose screening calculation is based on an assumption that an individual drinks 337 L/yr of water, rather than the more appropriate 730 L/yr (2 L/day). It is also not clear that the singular measure of risk should be the drinking water dose for radionuclides, if for some radionuclides, such as Se-79 and Sn-126, the dose attributable to other pathways is more dominant. The purpose of the key radionuclide list should be clarified.

Basis

Section 5.2.2 of the PA, describes the screening methodology used to determine which radionuclides were the most significant to dose, or key radionuclides. The results of the screening calculations are provided in Table 5.2-9. The screening calculation, which uses a minimum dose level as a threshold for determining key radionuclides, uses the product of the peak 100 m groundwater concentrations through the first 20,000 years, the ingestion dose conversion factor, and the water ingestion rate of 337 L/yr. As discussed elsewhere in the PA, a more appropriate deterministic value for ingestion rate assuming maximum consumption by a possible receptor is 730 L/yr. At a minimum, the use of this ingestion rate value would add I-129 to the Table 5.2-9 key radionuclide list.

Secondly, it is not clear that the use of the drinking water pathway alone through the first 20,000 years does not exclude radionuclides from the key radionuclide list. Key radionuclides are those radionuclides that contribute most significantly to risk to members of the public, including inadvertent intruders, workers and the environment. Only radionuclides for the groundwater pathway were provided in Table 5.2-9. NRC considers “key radionuclides” to be synonomous with the term “high radioactive radionuclides” used in the National Defense Authorization Act. If the intent of Table 5.2-9 is to generate the list of risk-significant radionuclides in a future WD, the list should be expanded to include non-groundwater dependent pathways.

Path Forward
Provide a technical basis for only using a drinking water dose to identify key radionuclides for groundwater pathways, and justify the use of the ingestion rate used for that analysis. Specifically list key radionuclides for non-groundwater dependent pathways or clarify the purpose of Table 5.2-9.

Comment IN-2
In the PA, DOE assumes that the volume of waste residuals in Tanks 18 and 19 will be reduced by seventy-five percent to reflect ongoing removal plans (page 202 of the PA). The PA does not provide supporting information regarding these removal plans or their assumed effectiveness.

Basis
Releases from Type IV Tanks 18 and 19 are the primary risk drivers in early simulation timeframes. The inventory for non-solubility limited radionuclides is directly proportional to the estimated doses from these radionuclides. A basis is needed to support the inventory estimates for Tanks 18 and 19.

Path Forward
The PA or supporting reference documents should contain additional information related to planned waste retrieval activities for Tanks 18 and 19 and the expected effectiveness of these activities.

Comment IN-3
The PA should provide additional information to support the inventory estimates for FTF tanks that DOE plans to treat with oxalic acid.

Basis
For many radionuclides that are not solubility limited, the inventory has a direct impact on the expected dose. For all tanks besides Tanks 17 through 19, the inventory estimates are based on radionuclide information in the Waste Characterization System (WCS), and an assumption that tank cleaning with oxalic acid will be effective in leaving only 0.0625 inch of residual heel. The depth estimate is based on experience with cleaning Tank 16 using oxalic acid, a cleaning process that DOE plans to use on remaining FTF tanks. No information is provided in the PA to support the assumption that future use of oxalic acid will be as effective in removing solids as it was for Tank 16 (e.g., oxalic acid is not expected to be as effective in treating certain solids such as zeolites present in some of the tanks).

West (1980) provides information on the expected effectiveness of oxalic acid treatment of waste tanks. The results in this report show that plutonium (Pu) and strontium (Sr) can be concentrated in the residual heel. Results of testing of oxalic acid effectiveness on sludge in Tank 5 also showed that oxalic acid may not be effective in dissolving Pu, although results were stated to be inconclusive (Hay et al., 2007). However, only a handful of key radionuclides are addressed in these two reference documents. In addition, it is not clear that the sample taken from Tank 5 for oxalic acid testing is representative of the waste in all the tanks where oxalic acid will be used to clean the tanks.

Path Forward
DOE could increase support for the assumption regarding the effectiveness of oxalic acid in cleaning FTF tanks by providing a summary in the PA of process history and any tank waste characterization efforts that indicate the tank contents of FTF tanks are similar in content to Tank 16 and that testing from Tank 5 samples are representative of waste in other tanks. If

particular tank waste is not expected to be similar to Tanks 5 and 16, additional characterization and testing would provide a defensible basis for the assumed effectiveness of waste retrieval operations.

Additional evaluation of the adequacy of use of volume estimates and pre-cleaning concentrations versus consideration of preferential treatment of oxalic acid in removing key radionuclides would also increase confidence in the inventory estimates.

Comment IN-4

The PA should contain additional information to provide support for key radionuclide concentrations that were estimated using WCS, and special calculations used to generate inventories for most of the tanks in the FTF. DOE should consider the uncertainty in inventory estimates that are based on WCS and special calculations to ensure that dose estimates for risk significant radionuclides are not underestimated.

Basis

As inventory estimates have a direct impact on the dose results for non-solubility limited radionuclides, it would be prudent for DOE to develop inventory estimates that err on the side of conservatism (or higher inventories).

The inventory estimates for tanks that have not yet been cleaned in FTF are based on WCS concentrations and assumed thickness of contamination expected to remain following cleaning with oxalic acid. It is not clear that the WCS provides an accurate estimate of the concentrations for many key radionuclides. For example, Figure 3.3-3 in the PA shows that for Tank 19, the WCS underestimates the concentrations of Cs-137 by up to three to four orders of magnitude (presumably due to the presence of zeolite in the tank), and the concentrations of Tc-99 by two orders of magnitude.

The PA states that Ra-226 is assumed to be in transient equilibrium with U-234. It is not clear why Ra-226 concentrations are higher than U-234 for most tanks and why Ra-226 concentrations are several orders of magnitude less than U-234 in Tanks 18 and 19. In the PA, U-233 was assumed to be in secular equilibrium with Np-237; however, is it not clear that the Np-237 concentration estimates are reliable (e.g., the footnote on Figure 3.3-3 states that WCS does not provide inventory estimates for Np-237 although sampling data comparison against Np-237 concentrations in the WCS are provided).

While uncertainty with respect to inventory is addressed in the stochastic analysis, it is not clear that the approach used is fully supported. Four inventories are used in the stochastic analysis to represent the uncertainty in the inventory estimates, with each equally weighted at twenty-five percent. The four inventories are as follows: (i) over-predicted by two orders of magnitude, (ii) over-predicted by one order of magnitude, (iii) the same as the estimates provided in the PA, and (iv) under-predicted by one order of magnitude. Because inventory uncertainty is expected to be tank- and radionuclide-dependent over a more continuous range, the basis for the stochastic distribution is not clear.

Path Forward

The PA should explain how uncertainties in the inventory estimates based on WCS concentration data and special calculation are managed and addressed in the deterministic analysis to prevent significant under-predictions of potential dose. DOE should provide additional support for the approach used to consider uncertainty in inventory estimates in the stochastic analysis, including the use of a discrete probability distribution.

Comment IN-5
The PA should contain additional information to support the inventory estimates for Tanks 18 and 19 and other tanks containing hardened zeolite (e.g., Tanks 7, 25 and 27).

Basis
As the inventory for non-solubility limited radionuclides has a direct impact on dose, the inventory estimates developed for risk-significant tanks such as Tanks 18 and 19 should be fully supported. It is not clear that sampling is sufficient to provide accurate inventory estimates for tanks such as Tanks 18 and 19, which contain hardened zeolites. The PA uses information on Cs-137 concentrations in zeolite obtained by sampling as a basis for developing inventory estimates for Tanks 7, 25, and 17. It is also not clear how volume estimates of hardened zeolite are derived and how the uncertainty associated with these estimates were considered. For example, undisturbed material in the center of Tank 19 was observed following bulk sludge removal. Because aged zeolite was observed to form hardened slabs and to settle faster than sludge, there is a potential to underestimate the presence of hardened slabs of zeolite on the bottom of the tank under the final liquid level (NRC, 2006b).

Path Forward
The PA should provide additional details regarding the sampling of hardened zeolite for the purposes of developing inventory estimates for Tanks 7, 18, 19, 25, and 27. The PA should also discuss the approach used to estimate volumes of zeolite present in these tanks.

Comment IN-6
The PA should provide more information on how the initial radionuclide inventory is calculated, including how daughter products are treated.

Basis
The PA should more clearly describe how inventories of daughter radionuclides are calculated. The PA states that the ingrowth and decay of daughter radionuclides are calculated by PORFLOW and GoldSim, so that, even if they are not assigned an initial inventory, they will, nonetheless, be addressed. However, because it may take tens of thousands of years for certain radionuclides to grow-in and the simulation time period is limited, the fact that PORFLOW and GoldSim will calculate daughter in-growth is not, by itself, a sufficient basis for not assigning an initial inventory.

Table 4.2-4 of the PA (page 255) lists two radionuclides, Ra-228 and Th-232 (out of a total of fourteen radionuclides), from the four principal decay chains that will be assigned an initial inventory. Section 4.2.1.2 states that the same two radionuclides were shown by special analysis not to be present in the dry sludge, and were not, therefore, included in the initial inventory. It is not clear how the list of fourteen radionuclides assumed to be initially present is determined. Likewise, Cm-243 (a parent radionuclide in Table 4.2-3) is not listed among radionuclides that are assumed to be present initially, but it is found in Table 4.2-5 as one of the sixty-four radionuclides to be considered in the analysis. Inventories for Cm-243 are presented in Table 3.3-2; however, the table contains a footnote which states that Cm-243 inventory is based on a special calculation. No additional information is provided on page 218 of the PA which describes how inventories are estimated using special calculations.

Path Forward
The basis for inclusion or exclusion of radionuclides in the four decay chains as initially present and a description of how daughter products are considered (e.g., Pb-210 is listed as a key

radionuclide in Table 5.2-9 but is not specifically listed in the table of 64 radionuclides) should be provided in the PA. Clarify if Ra-228 and Th-232 are assumed to be initially present consistent with Table 4.2-4, or not considered in the analysis as stated in the text of Section 4.2.1.2 on page 256 of the PA. Clarify if Cm-243 is assigned an initial inventory as indicated in Table 3.3-2, and describe the special calculations for radionuclides that are not in the WCS but are listed in Table 4.2-5.

Comment IN-7

The PA should provide additional information in support of source term assumptions for transfer lines.

Basis

The source term for the drill cuttings in the intruder-driller scenario is a 3-inch diameter portion of the transfer line which is intersected when drilling for a well. The transfer line source term is modeled by distributing the assumed inventory equally over all of the transfer lines in the FTF. However, the calculations for the assumed inventory in the transfer lines need further explanation. DOE states, “The results of a review of waste transfers within FTF and between FTF and H-Tank Farm (HTF) have been sorted to determine the percentage of the volume of all waste transfers that can be attributed to each FTF waste tank” (page 222). The weighted concentration of radionuclides in the slurried sludge is presented in Tables 3.3-5 (page 223). However, the weights for the individual tanks are not provided. It is not clear how much credit is being taken for less or more waste being transferred from each tank.

Path Forward

The PA should provide more details of the calculations that determine the volume of waste from each tank that was assumed to travel through a certain percentage of the transfer lines. Because the reliability of the historical data on which the weighting factors are based is not clear, DOE could conduct a sensitivity analysis by assuming that all the waste was routed through all the transfer lines. The analysis could apply the maximum slurry concentration (20% of the dry sludge) of each radionuclide from each tank as the source term for the transfer lines.

Comment IN-8

The PA should provide additional information to support the equation used to describe the residue that remains after flushing the lines.

Basis

Approximately 99% of the source term inventory in the transfer lines is the residue that remains after flushing. An important assumption in the calculation of the residual inventory remaining after flushing is that “the waste concentrations follow an exponential decay curve with respect to time” (Caldwell, 1999). Caldwell, 1999, describes a calculation, “to estimate the time it takes for the sludge exiting HPT-7 to drop to less than 5% of the steady state concentration.” The calculation has several assumptions (e.g., uniform and well-known incoming sludge concentration and homogeneous, well-mixed system) that may limit the applicability of the exponential model for residue remaining in the piping.

Path Forward

DOE should assess the risk-significance in the twenty-fold decrease in the inventory based on the assumed effectiveness of transfer line flushing. Commensurate with the expected risk-significance of the reduction in the estimated dose to a member of the public (including inadvertent intruders), DOE should provide adequate support for the model selected to calculate the final residual concentration (and inventory) in the transfer lines (e.g., use of a continuously stirred tank versus plug flow reactor model) and reduce or evaluate the uncertainty in the dose predictions based on use of an analytical model that may not adequately represent reality.

Comment IN-9

The PA should evaluate the risk-significance of field survey data of the residual radioactivity in the transfer lines.

Basis

A reference cited in the PA states that the analytical results for residual concentration of waste in transfer lines were compared to results from standard characterization techniques using field surveys (Caldwell, 2005, page 11). The results from the field surveys were not evaluated in the PA. The results show that some of the radionuclides were found to have a higher concentration than estimated using the analytical approach.

Path Forward

Determine the risk-significance of the field survey data by substituting it for the calculated analytical residual concentrations for those isotopes. If the resulting dose for the intruder scenario is over 500 mrem, or the groundwater all pathways dose is greater than 25 mrem, explain why the field survey results were not discussed in the body of the PA (e.g., large error or uncertainty associated with field survey results).

Clarifying Comments—Inventory

Clarifying Comment IN-10

Inventories related to corrosion products on tank walls are based on an assumed linear partitioning. An expected range of values for the uranium distribution coefficient was provided in Kaplan (2006b) (i.e., K_d is expected to be two to three orders of magnitude lower than the earlier value of 6000 L/kg). Limited data is provided in the range of pH expected in the tanks (pH 12-14) and a basis for the two to three order of magnitude reduction in K_d values is not provided (e.g., it is difficult to extrapolate the results of data presented in the reference). It is also not clear what value was selected for the final inventory calculations. Provide additional details on what final value for the U distribution coefficient was selected and a clearer basis for this value.

Infiltration and Erosion Controls

DOE evaluates the performance of engineered surface barriers in its PA, which will be designed to limit the amount of water infiltration into the waste tanks. Water infiltration is usually a very sensitive parameter value in performance assessments, because it is directly related to the flux of contaminants into groundwater. The following comments are related to the assumptions in the engineered closure cap performance and degradation modeling, that effect the timing and magnitude of water infiltration over time. Erosional processes can compromise the performance of the engineered closure cap; for sites where erosion is a concern, it is important to consider erosion controls to protect the integrity of the engineered surface barriers relied on to limit infiltration. Thus, several comments related to erosion controls are also provided below.

To develop the following comments, staff reviewed the PA and supporting documents provided to NRC by letter dated August 20, 2008 (Spears, 2008). The staff's review criteria pertaining to infiltration and erosion controls are contained in sections 4.2, 4.3.1, 4.3.2, 4.4, and 4.6 of NUREG-1854, "NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations" (NRC, 2007).

Comment IE-1

The PA should more fully describe important factors affecting the performance of the proposed engineered closure cap (e.g., contribution of cap layers to evapotranspiration [ET] rates).

Basis

Chapter 3 of the PA summarizes important conceptual processes pertaining to the proposed engineered closure cap that are more fully documented in Phifer et al. (2007). Phifer et al. (2007) also includes simulation results for various closure cap designs that are similar to the proposed engineered closure cap presented in the PA. These simulations provide insight on how the overall cap system will limit water infiltration. Evapotranspiration is significant from the standpoint that it prevents approximately 70% of the total amount of precipitation from becoming infiltration water. Therefore, it is important to understand how various layers in the system affect ET rates. For example, results of simulations conducted for a design that does not include a lateral drainage layer (configuration #4) shows the impact of the lateral drainage layer on ET rates. The results of the simulation show that the ET rate is significantly increased if the lateral drainage is absent (36.5 inches for configuration #4 versus an average of 33.5 inches for all other configurations where the lateral drainage layer is present). Thus, the presence of the lateral drainage layer in the proposed design appears to affect the ET rates in the evaporative zone, which is the top 22 inches of the closure cap, even though the lateral drainage layer is located 60 inches below grade.

Path Forward

More detailed information regarding the conceptual process of ET within the proposed engineered closure cap should be provided including an explanation of how a lateral drainage layer located 60 inches deep affects ET, even though the ET zone depth is 22 inches. Additional information on how components of the closure cap affect one another will provide greater risk-insights into the significant processes occurring in the closure cap.

Comment IE-2

The PA should provide information on shorter-termed seasonal/transient effects and intense precipitation events on cap performance. In addition, the PA does not address the anticipated effects of potential changes in climate on the closure cap.

Basis

The relevant environmental factors, such as rainfall or ET, are based on average annual values, which don’t take seasonal variations into account. The resulting water budget and, in particular, the amount of infiltration, may change with changes in environmental factors. For example, lower ET rates during winter, due to lower plant growth and lower transpiration, may cause increased infiltration rates. Intense precipitation may overwhelm the engineered closure cap, allowing water to move past the evapotranspiration zone before the vegetation cover would normally have the opportunity to remove it. Lateral flow could potentially occur on top of the erosion barrier during intense precipitation events, which could cause erosion of the soil layers above the erosion barrier and affect the overall water budget of the system.

The potential for variation of long-term weather patterns could result in significant changes to the runoff, erosion of the top soil and upper back fill, or infiltration rates of closure caps. For example, long-term weather patterns may be cyclic: drought-like conditions followed by more humid conditions followed again by drier conditions. Such cyclic conditions may influence numerous parameters such as vegetation type, erosion rates, degradation rates, infiltration and recharge rates. Changes in one parameter may affect other parameters (e.g., increased erosion may reduce the zone of evapotranspiration and/or increase root penetration or the erosion barrier).

Path Forward
The PA should contain information on the effects of short-term, seasonal and transient weather patterns and intense precipitation events on the performance of the engineered closure cap and resulting infiltration rates through the cap, or state why these variations and intense events do not need to be considered. In addition, the PA should address the anticipated effects of potential long-term changes in weather patterns on the closure cap. The level of detail provided in the PA would depend on the sensitivity of the model results to these variations and events. If the simulated runoff, erosion, or infiltration results are sensitive to wetter or drier climates, those impacts should be considered. Changes to the conceptual process model caused by the effects of different variations in weather patterns should be documented. For example, removal of a portion of the surface layer may affect the infiltration rate which may affect the degradation rates.

Comment IE-3
The PA should provide additional support for the assumption that the protective erosion barrier remains intact for 10,000 years.

Basis
The closure cap soil/backfill, erosion barrier, side slope, and toe of the side slope have been designed to be physically stable relative to erosion potential consistent with NUREG-1623 (NRC, 2002). While the slope and slope length of topsoil and upper backfill layers have been specified to prevent initiation of gullying, these layers are assumed to be subject to erosion. The 3-ft deep erosion barrier and the layers below are not assumed to be subject to erosion. Burrowing animals are likewise prevented from damaging deeper layers (e.g., the geotextile fabric layers and the high density polyethylene [HDPE] geomembrane layer) according to Table 3.2-9 in the PA. This makes the erosion barrier an important barrier for closure cap performance: providing physical stability to the closure cap, sufficient water storage for ET promotion, and a minimum of 10 ft of material above the tanks to deter intrusion into the disposal facility for 10,000 years.

Tree roots with a given diameter and volume range are expected to penetrate the erosion barrier, which may loosen the erosion barrier compactness. Decomposed roots, especially those of the 12 ft tap root, may allow access paths for burrowing animals through the erosion barrier. Bioturbation may have a similar effect. These processes may compromise the functionality of the erosion barrier as listed above and should be evaluated.

Path Forward
The PA should provide additional support for the assumption that the erosion barrier will remain effective in preventing damage to deeper cap layers, given the potential for root and animal penetration for 10,000 years. Model assumptions and parameter values should be well documented and supported commensurate with their risk significance. Independent lines of evidence are a form of model support and can take the form of experimental results, documented analogs, or expert elicitation that substantiates the model assumptions used.

Comment IE-4
The PA should provide additional support for the assumption that the hydraulic conductivity of the combined layer remains constant for 10,000 years (Table 64, page 185; Phifer et al., 2007).

Basis

The high-density polyethylene (HDPE) geomembrane and geosynthetic clay layer (GCL) were modeled as a combined layer with a hydraulic conductivity of 8.7×10^{-13} cm/s after the year 299. Phifer et al. (2007) developed a conceptual model in which degradation processes create holes through this combined layer, resulting in an increasing number of holes over time. However, the combined layer is assumed to remain otherwise intact and nearly impermeable. Considering the uncertainties still associated with this material, the relatively short time period in which it has been in use, and the relatively long time period for which it will be used (10,000 yr), the PA should provide more support for the assumption of constant hydraulic conductivity. This assumption appears to be unrealistic and potentially non-conservative, if it prevents a significant amount of water from becoming infiltration water.

Path Forward

The PA should provide additional support for the assumption of a time-invariant hydraulic conductivity for the intact portion of the combined layers (e.g., demonstrate that infiltrating water is fully conducted through the holes in the combined layer, or show that the approach used is realistic or otherwise conservative). Model assumptions and parameter values should be well documented and supported commensurate with their risk significance. Independent lines of evidence are a form of model support and can take the form of experimental results, documented analogs, or expert elicitation that substantiates the model assumptions used.

Comment IE-5

The PA should provide additional information and analyses for the design of the integrated drainage system referenced in Section 4.4.15 (page 56) of Phifer et al. (2007).

Basis

The NRC staff recognizes that the design of the integrated drainage system (diversion channels and diversion structures) has not yet been finalized, as DOE indicates in Section 4.4.15. However, the design of the erosion protection for the ditches and the ultimate discharge areas for surface runoff may be important in the evaluation of the overall performance of the closure cap.

DOE should consider the following topics as it develops final designs and supporting documentation for the diversion channel system selected for use at this site, which show the locations of important structures and drainage paths of all surface runoff from the cap. Supporting calculations should be developed for the following design features:

a. Channel Design. The diversion channels and the erosion protection for the channels should be designed for the Probable Maximum Flood (PMF), similar to the closure cap. Values of the PMF should be developed for the ditches, design methods, water surface profiles, and channel slopes.

b. Sediment Accumulations. The channels should be designed to be self-cleaning and should flush/remove any expected accumulations of sediment. In general, this means that the channels will need a relatively steep slope to produce adequate flushing velocities and will require relatively large riprap to provide stability from those high velocities. Alternately, DOE could show that sediment accumulations in the ditches will not affect the stability of the closure cap, even if the ditches were to completely fill with sediment.

c. Channel Exit Velocities. In those locations where the diversion channels discharge to natural ground, it may be necessary to provide riprap-protected aprons and outlets to reduce exit velocities to acceptable levels and to protect the channels from gully intrusion. DOE should consider design features for those areas where the diversion channels discharge to natural ground.

d. Hydraulic Jumps. If steep channel slopes are used in the design, it may be necessary to locate and design for hydraulic jumps that would occur where the flows transition from supercritical to subcritical. DOE should accommodate these phenomena in future designs.

e. Channel Bends and Curvature. If the diversion channels are curved, it may be necessary to design the channels for increased shear stresses that could occur on the outside of the channel bends. DOE should take into consideration design features that are necessary to provide adequate protection on the outside of the channel bends.

Path Forward
DOE should consider erosion protection design for the integrated drainage system, fully documenting the ability of the design to accommodate: (a) shear stresses and velocities produced by an occurrence of a PMF; (b) potential sediment accumulations; (c) exit velocities from the diversion channels as they transition onto discharge aprons and onto natural ground; (d) hydraulic jumps; and (e) increases in shear stresses in areas of channel curvature.

Comment IE-6
Rock durability criteria in the PA do not appear to include all of the factors important to performance.

Basis
Two rock durability criteria are identified in Section 4.4.9 of Phifer et al. (2007) that will be used for eventual evaluation of the source of durable rock. In addition, Section 4.4.9 indicates that natural or archaeological analogs will be researched to help demonstrate the closure cap physical stability with regard to erosion over 10,000 years.

NRC's decommissioning guidance in NUREG-1757, Appendix P (NRC, 2006a) adds to previous NRC guidance in NUREG-1623 (NRC, 2002) and provides NRC's most recent guidance regarding selecting and evaluating durable rock for erosion covers. NUREG-1757 criteria were expanded beyond the testing and scoring in NUREG-1623 to specifically address the long-term durability of rock for erosion covers. NUREG-1757 describes three evaluations of rock durability that should be conducted to provide multiple and complimentary lines of evidence and greater confidence in the future durability of the rock source selected. These criteria/evaluations are: (1) rock durability testing and scoring from NUREG-1623 (similar to the second criterion in Section 4.4.9); (2) absence of adverse minerals and heterogeneities (similar but broader than the first criterion in Section 4.4.9); and (3) evidence of resistance to weathering using both direct evidence from the selected rock and indirect evidence from comparisons of the selected rock to similar rock types (i.e. natural and archeological analogue sites). Although DOE's criteria together with the analogue research described are similar to NRC's three criteria, they are missing some important information and detailed guidance. For example, the second NRC criterion focuses on absence of adverse minerals and heterogeneities and is similar to the SRS proposed criterion that focuses on absence of defects, but only as determined by a petrographic examination. The SRS proposed criteria do not include an evaluation of the absence or presence of observed heterogeneities on a large scale in the quarry that could reduce durability or limit obtaining the required rock size. For example, after selection of the source rock type and specific quarry, the list of factors in Section 4.4.9 should be revised to identify specific features of the selected quarry such as veins, coarse-grained or pegmatite zones, xenoliths of country rock, and banding resulting from mineral concentrations such as micas. In addition to evaluating these adverse features under this criterion, it should also be explained that these adverse features would also be identified in the rock production procedures as features to identify and avoid during rock production. The third criterion on direct and indirect evidence of resistance to weathering ties in well to the natural and archaeological analog studies that SRS proposes that provide indirect evidence. However, direct evidence from the specific rock source itself is missing and should be included if such evidence, such as observed weathering or measured weather rates, can be obtained from natural exposures of the selected rock.

Path Forward

The SRS proposed two criteria and analogue work described is generally consistent with the NUREG-1757 criteria. NRC recommends that DOE combine and reorganize the discussion of criteria to be consistent with the three criteria listed in NUREG-1757 as well as the more limited ASTM criterion already referenced.

Comment IE-7

The PA should provide a technical basis or approach for determining rock size and erosion layer thickness that is appropriate for a 10,000 year erosion cover design. Furthermore, a preliminary evaluation of a rock source should be provided.

Basis

Page 51 of Phifer et al. (2007) indicates that the results of natural or archaeological analog evaluations will be used to increase the size of the emplaced stone and the thickness of the stone layer, if necessary, to accommodate anticipated weathering in order to ensure closure cap physical stability with regards to erosion over 10,000 years. Related to this, an open issue is identified in Section 3.2.4.8 of the PA for determining the estimated weathering rate of the erosion barrier stone based on natural or archaeological analogs and available literature. Although many references are provided for below and above grade weathering studies that might be good analogues for the durability of granite, many are qualitative and only give a general indication of long-term durability. While these could be useful, more quantitative weathering rate studies in addition to the one reference would be more useful, such as for saprolite formation rates or weathering rind formation rates. In addition, no approach or specific method is described for how the referenced studies would be used to estimate the amount of rock oversizing needed for 10,000 years. While using analogues seems reasonable, it should be noted that standard methods for 10,000 years are not available and are not provided in NRC guidance, which focuses on performance for 1,000 years. Furthermore, uncertainties in any method proposed would need to be discussed and considered in estimating the oversizing amount. In addition, preliminary information is not provided in the PA that would give some confidence that the rock source(s) mentioned are likely to be acceptable for the 10,000 year period.

This discussion about oversizing to account for rock weathering over 10,000 years raises another question about the basis for determining the design of the erosion cover, specifically the rock size and thickness appropriate for a 10,000 year period. This compliance time period is longer than the 1,000 year stabilization and compliance period that NRC's guidance was developed for under 10 CFR Part 40 contained in NUREG-1623 (NRC, 2002) and under 10 CFR 20 Subpart E contained in both NUREG-1757 (NRC, 2006a) and NUREG-1623 (NRC, 2002). No justification is given for using the 1,000-yr erosion cover design approach for the 10,000 year period.

Path Forward
The PA should either describe a general approach or commit to developing a method for using available rock analog studies to estimate the weathering rate and rock oversizing amount appropriate for the rock that might be selected. NRC staff recommends adding a preliminary evaluation of the rock sources proposed to provide some confidence that an acceptable rock source is likely to be available that would remain effective for the 10,000 year period. Consider: 1) providing a brief description of each rock source being considered and characteristics of the rock type and its quarry source that appear favorable to durability and rock production and; 2) calculating a preliminary rock score using durability test data that might be readily available from the existing quarries and combining these results with the natural analogue information already discussed in this section.

In addition, for purposes of completeness, provide a basis for using NRC's 1,000-yr guidance for an erosion control design for the 10,000-yr stabilization period. Consider explaining how using a bounding type event such as the PMP or PMF with an extremely low probability of occurrence also provides assurance of stability for 10,000 years. Discussion of this approach is provided in Section 2.2.1.2 of NUREG-1623 (NRC, 2002).

Clarifying Comments—Infiltration and Erosion Controls

Clarifying Comment IE-8

Provide citations in the text of Phifer et al. (2007) to support assumptions made in Section 7.5.1. Include supporting citations in Section 7.2 with the discussions of the age, depth, and diameter of the pine roots (page 117) and the movement of loblolly pine across grassed areas towards the closure cap by means of gravity/wind movement only (pages 116-117). Include references associated with the bullet statement in Sec. 7.4.2 on page 125: the instances of the uprooted wind-thrown loblolly pine trees "tend to be isolated and infrequent and will therefore have minimal impact on the erosion barrier as a whole."

Clarifying Comment IE-9

In Phifer et al. (2007), clarify the following contradicting statements: the third bullet on page 312 stating, "Deep roots will be maintained and enlarge with yearly growth over the life of the tree," with that part of Sec. 7.6.6 stating that roots "are not known to enlarge existing geomembrane defects" (Phifer et al., 2007).

Clarifying Comment IE-10

In Phifer et al. (2007), clarify and discuss the conceptual process model for decreasing cap performance [Table 80, page 221]. The PA or its supporting references should clarify whether water infiltration through the GCL increases because of the decreasing hydraulic conductivity of the lateral drainage layer or because of the increasing number of holes in the HDPE geomembrane. Staff also recommends that the PA include a sensitivity analysis, commensurate with the risk significance of the engineered cover. NUREG-1757 provides guidance for this type of analysis, which could be used to identify the components of the cover that are significant barriers, the significance of barrier degradation and timing, and to provide confidence in a transparent, well-described conceptual process model.

Near-Field Comments

DOE constructed a PORFLOW model that includes the grouted tank system located in the vadose zone at FTF. Comments related to tank system performance modeling assumptions including the hydraulic and chemical performance of the steel liner, concrete vault and basemat, and grouted tank that cumulatively assist with limiting waste release into the environment are addressed in the near-field comments. Several process sub-models are included in the near-field modeling (e.g., cementitous material degradation, geochemical modeling, and steel liner failure modeling). Together these sub-models comprise inputs or modeling assumptions in the PORFLOW near-field model.

Several comments related to corrosion modeling of the steel liner and piping are provided below. These comments include information requests to support the models and modeling parameters used to calculate failure times for the steel liner and piping. Steel liner performance is important for short-lived radionuclides because it can significantly delay releases from the engineered system. The distributions developed for the steel liner failure are also important in the probabilistic analysis as they dictate the timing of failures from individual tanks and piping that may cumulatively impact the peak of the mean dose.

Several comments address cementitious material degradation assumptions and its impact on chemical and hydraulic performance of the engineered system. Degradation of the waste form can increase the volume of water that may contact the waste, as well as change the type of mechanism that dominates the release of the wasteform, therefore influencing the risk. These comments are related to the chemistry of the pore water (e.g., solubility and sorption control), physical degradation of the grout (including the use of the Geochemist's Workbench calculations for predicting chemical transition times), and the relationship between the hydraulic and chemical transitions. These comments also address the impact of how cementitious material degradation is implemented in the conceptual models for tank configurations.

DOE assumes a solubility-limited release model for the contaminant zone. Solubility limits for key radionuclides can vary over many orders of magnitude, lending gravity to assumptions regarding chemical solubility. Comments related to solubility include the choice of chemical phase (including the thermodynamic database and computer code used for solubility calculations), treatment of intermediate pH waters, tank dip sample concentration measurements for establishing Tc and Se solubility, and the use of Fe coprecipitation model used for establishing Tc and U solubility.

Several comments are related to the assumed sorption coefficients in the cementitous materials, and other assumptions relating to the basemat thickness and distribution. The basemat is assumed to retard radionuclides after they are released from the contaminant zone. Specifically, these comments are related to the chemical conditions applied during experiments to establish K_d values, standard deviations for K_d values, and the K_d assumed for potentially risk-significant radionuclides under reducing conditions.

To develop the following comments, staff reviewed the PA and supporting documents provided to NRC by letter dated August 20, 2008 (Spears, 2008). The staff's review criteria pertaining to near-field release of radionuclides are contained in sections 4.2, 4.3.2, 4.3.3, 4.4, and 4.6 of NUREG-1854, "NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations" (NRC, 2007).

Comment NF-1

The PA should describe the rationale for the adequacy of the assumption that cementitious material properties (i.e., bulk density, porosity, and water retention) are time-invariant.

Basis
The properties of degrading cementitious materials are expected to vary with time as the degradation proceeds. The PA does not provide a clear description of the technical basis for fixing bulk density, porosity, and water retention.

Path Forward
The PA should provide justification for the adequacy of the assumption that cementitious material properties (i.e., bulk density, porosity, and water retention) are time-invariant. This could be accomplished by demonstrating that the reasonable time variance of these parameters does not significantly impact the releases and resulting health impacts.

Comment NF-2
The version of GoldSim used for calculations presented in this PA simulates contaminant transport of non-radioactive and radioactive isotopes independently. GoldSim can simulate transport parameters (e.g., partitioning coefficients, solubility limits) on an elemental, not isotopic, basis. Therefore, this implementation in GoldSim does not accurately account for the combined effects of both stable and radioactive isotopes on the transport of an element. A description of the effects of the GoldSim implementation of non-radioactive contaminants on radionuclide release and transport would support a defensible conceptual model.

Basis
Section 4.4.4.2 of the PA describes the GoldSim modeling process in general and specifically discusses the treatment of non-radioactive elements which may be both radioactive and non-radioactive in the model. The description specifically mentions Pb as an example of such an element. The implementation described does not relate the non-radioactive species to the radioactive species which can affect transport calculations (e.g., solubility, sorption).

Path Forward
The PA should provide a description of rationale for treating non-radioactive species distinctly from radioactive isotopes of the same chemical element.

Comment NF-3
The PA should describe the process for the use of expert judgment in a way that would enhance transparency of the waste release model.

Basis
Expert judgment is integral to the estimation of the likelihood of significant parameters in the waste release model. For instance, expert judgment was used in the PA to assign: The 1) likelihood of solubility limiting phases in section 4.2.2.3; 2) the likelihood of alternate configurations of the waste tank evolution in section 5.6.3.1; 3) uncertainty in the sorption coefficient (i.e., K_d for radionuclide migration through the basemat in section 5.6.3.4; 4) uncertainty in the likelihood of basemat bypass in section 5.6.3.6, and; 5) the uncertainty range for transition times between chemical states in the contaminated zone in section 5.6.3.8.

The use of expert judgment can compliment existing information when it is not feasible to collect data by other means. However, expert judgment should be viewed as an alternative and employed when other means of obtaining data have been thoroughly considered. When relying on expert judgment, DOE should develop sufficient documentation to allow external review of how judgments were made, how the judgments were used, and why the judgments were used instead of obtaining objective information. For expert judgment to be defensible, the basis for the judgment should be documented and traceable from the origins of specific initial assumptions through integration of the results and conclusions. Any calculations, models, and literature used by an expert to form a judgment should be documented. Any subsequent manipulation of expert judgments should also be documented. Documentation of the judgment process is particularly important for the parameters in the waste release model described above.

Path Forward
The PA should provide adequate traceability for the use of expert judgment to define solubility limiting phases, the likelihood of alternate configurations, the likelihood of basemat bypass, the sorption coefficients for radionuclide transport through the basemat, and the uncertainty in transition times between chemical states in the waste release model.

Comment NF-4
The PA should contain a more appropriate treatment of spatial variability in the basemat thickness, which would improve the sensitivity and uncertainty analyses.

Basis
Section 5.6.3.5 of the PA describes the rationale to account for variability in basemat thicknesses amongst the various tank types. Spatially averaged thicknesses were estimated for Type IV tanks because drainage channels cover approximately six percent of the basemat surface. The estimates of the basemat thickness for the Tank Type IIIA did not account for the channels on the surface of the basemats. A range of basemat thickness was sampled from a triangular probability distribution for each tank type. The NRC staff believes that assigning a distribution of basemat thicknesses to account for the presence of channels may not be an appropriate methodology, particularly in regards to estimates of the transport of shorter-lived radionuclides. A more appropriate treatment would involve distinguishing between uncertainty and variability in the basemat thicknesses. The uncertainty in the thickness of the basemat could be determined based on the known tolerances for concrete installation where channels and other spatially-variant features are located. Variability in basemat thickness could be accounted for by assigning a likelihood to radionuclide transport through various types of basemat features.

Path Forward
The PA should contain a more appropriate treatment of the spatial variability in the thickness of the waste tank basemats for the various tank types.

Comment NF-5
The PA should describe the construction materials used below Type I tanks, such as plaster and waterproofing membranes, and provide a rationale for excluding their effects on radionuclide transport.

Basis
Section 3.2.1.1 of the PA describes the construction of Type I tanks. Section 5.6.3.5 describes the estimation of the thickness of Type I tank basemat thicknesses for uncertainty analyses. The thickness of plaster and membrane waterproofing material is included in the estimation of basemat thickness. A description of the materials comprising this membrane and their effect on radionuclide migration through the basemat is not included. The inclusion of the thickness of these materials as a portion of the basemat thickness implies that the their properties are materially similar to those of the basemat concrete. There is insufficient information in the PA to support this assumption. If radionuclide transport properties of the plaster and membrane are

expected to be different than basemat concrete properties, then the effects of these layers should be discussed separately.

Path Forward
The PA should provide a description of the membrane material properties, whether their treatment as part of the basemat is reasonable, and their anticipated effects (e.g., solubility, sorption, etc.) on radionuclide migration through the basemat below Type I tanks.

Comment NF-6
The technical basis in the PA for the assumed chemical transition from Oxidized Region II to Oxidized Region III should be enhanced to better explain the relationship between infiltrate pore volumes and pore water pH.

Basis
The description of the chemical degradation of the reducing grout in Section 4.2.2.6 of the PA is based upon the description of the geochemical analyses described in Denham (2007). Denham (2007) describes the linear extrapolation of the number of pore water volumes necessary to dissolve the entire mass of CSH before pH transitions to lower values. The basis for the linear extrapolation is a linear relationship between CSH mass and pore volumes from the model that results in a transition sometime after the end of the simulation at 350 pore volumes. No technical basis is provided for extrapolating the linear relationship beyond 350 pore volumes. Also, the basis for selecting the pH transition when the entire mass of the CSH is consumed is not provided.

Path Forward
The PA should provide a basis for linearly extrapolating remaining CSH mass beyond which is present at 350 pore volumes to zero remaining CSH mass that is used to estimate the number of pore volumes that must pass through the grout before the pH of the pore water transitions to lower values.

Comment NF-7
The technical basis in the PA should be enhanced for the assumptions used to estimate the normative mineralogy of the hydrated grout presented in Section 4.2.2.6 (Chemical Degradation of Reducing Grout). In particular, support for the following assumptions should be enhanced: all calcium in the grout components ends up in the CSH; all magnesium ends up in hydrotalcite; and the excess aluminum ends up in gibbsite.

Basis
Gibbsite is not typically present in hydrated cement-based materials. For hydrated Portland cements, the minerals typically present are portlandite, CSH, ettringite, and monosulfate (Berner, 1992). In slag–cement blends, Glasser, et al. (1988) observed the following phases: portlandite, gehlenite hydrate, a hydrotalcite-structured phase (nominally $6MgO \bullet Al_2O_3 \bullet (OH)x \bullet yH_2O$) , an AF_m-type phase (nominally $4CaO \bullet Al_2O_3 \bullet SO_3 \bullet 12H_2O$), and a poorly crystallized CSH. Because the mineralogy used in modeling grout degradation determines the pH evolution of grout pore water, which in turn affects the calculated radionuclide solubility, using an incorrect mineralogy in the model could lead to nonconservative solubilities and releases of radionuclides from the contaminated zone.

Path Forward
The PA should provide additional information supporting the assumptions used to derive the hydrated grout mineralogy, or supporting calculations demonstrating that using mineralogy

consistent with observed mineralogy of hydrated slag–cement grout does not change significantly the calculated radionuclide solubilities. An alternative approach to calculating the mineralogy of hydrated slag–cement blends is presented by Atkins, et al. (1992a,b).

Comment NF-8

In the PA, more support should be provided for use of the equation used to compute the area breached by pitting corrosion of carbon steel (liners and transfer lines).

$$A_b = N_p \pi (h^2 - d^2)$$

where: A_b = Area breached (m^2)
N_p = penetrating pits per container (pits/m^3) – assumed to be 5000 per m^2
h = maximum pit depth (m)
d = corrosion allowance

Basis

The area breached by pitting corrosion is assumed to be described by a parabolic function of the penetration depth. The area breached starts at zero when the “first pit” front penetrates the thickness, *d*, and then the area breached grows as the penetration depth, *h*, exceeds *d*. The time to failure of the steel transfer lines is defined as the time it takes for 25 percent of the surface to be compromised by pitting (page 6; WSRC, 2007). It is implied that 100 percent of the area needs to be breached to constitute failure of the steel liner in the text discussing Figure 18 of the steel liner corrosion report (page 35; SRNL, 2008), which compares the time to penetration of the steel liner from general corrosion to the area breached from pitting corrosion[1]. The derivation and geometric interpretation of the breached area equation is not provided in Savannah River National Laboratory reports (SRNL, 2007, 2008), nor is a reference provided discussing its range of validity.

The penetration depth, *h*, of the corrosion pit front was computed as a power function of time (SRNL, 2008, page 31; 2007, page 14). If the penetration depth is representative of an ensemble of pits, simultaneously propagating at multiple spots on the steel surface, it is unclear why the time to failure was not simply defined as the time it takes the penetration depth, *h*, to equal the thickness of the steel structure.

In general, pit initiation, pit growth, and pit distribution are stochastic processes (e.g., Budiansky et al., 2005; Lunt et al., 2002; Shibata, 2000). It is unclear why a closed-form equation is an appropriate equation to predict damage by pitting as a function of time.

Path Forward

The PA should provide a derivation, including a discussion of limitations and the range of applicability, of the area breached equation:

1. Discuss why it is appropriate to define the time to failure as the time it takes for a computed fraction of the surface area to be compromised by pitting, as opposed to defining the time to failure as the time it takes the penetration depth to equal the thickness of the steel structure; and

---

[1] While pitting corrosion is evaluated, this mechanism is not considered for corrosion of the steel liner. Comments NF-11 and NF-12 request additional information regarding evaluation of this degradation mechanism for steel liner failure.

2. Discuss the technical basis for implicitly assuming that pits arise in a narrow region and then propagate in space, as opposed to assuming that pit regions may initiate simultaneously on multiple locations of the steel surface.

Comment NF-9

The PA should evaluate uncertainty in the pit penetration depth of carbon steel (liners and transfer lines) as a function of time (SRNL, 2008):

$$h = 56.56(t)^{0.3205}$$

where h=pit depth (mils)
t=corrosion time (years)

Basis

The parameters of the power function to define the pitting depth as a function of time are based on literature reviews. The power function is an empirical function, with parameters derived from short term experiments. In general, such empirical functions are extrapolated in time to estimate the time of failure of engineering structures with lifetimes of a few years to a few decades. Extrapolation beyond those time frames should be exercised with caution. For example, Figures 17, 19, and 21 in SRNL (2008) showing the penetration depth versus time indicate that the corrosion rate associated with pitting eventually falls below the general corrosion rate after a few hundreds of years (i.e., the slope of the pitting corrosion curve is eventually less than the constant slope of the general corrosion curve). It is not physically clear why the corrosion rate associated with pitting can fall below the general corrosion rate. It would be more physically reasonable to assume that the pitting corrosion rate is greater than the general corrosion rate. A potential lower limit in the pitting corrosion rate may not be detectable from short term experiments.

The NRC staff also observed that the analyses by the Savannah River National Laboratory (2008, 2007) contained no consideration of uncertainty in the power function parameters. Uncertainty in the constant and the exponent can result is significantly different predictions of the time to failure.

Path forward

Additional information should be developed for the PA which evaluates:
1. Changes in the failure time if a minimal value in the pitting corrosion rate was assumed; and
2. The effect of uncertainty of the power function parameters on the time to pit penetration.

Alternatively, the PA should provide the technical basis for not propagating uncertainty in these parameters, or not assuming a minimum value in the pitting corrosion rate, if this information is available.

Comment NF-10

The equation used in a supporting reference to the PA (SRNL, 2008) predicts that the rate of penetration of chloride in concrete is based on research of concrete in highways. It is not clear if that equation is appropriate to compute the time of steel depassivation by chloride.

Basis

The equation to estimate the time to depassivation of steel by chloride is discussed in Section 3.3.2 of SRNL (2008, page 25). The empirical equation derived from research sponsored by the Federal Highway Administration (Clear, 1976) was argued to be a broadly accepted methodology (SRNL, 2008, page 25). However, NRC staff is aware that alternative approaches exist in the literature to compute the time of initiation of corrosion by chloride. For example, Liang, Lin, and Liang (2002) compiled equations from other authors to estimate the time for initiation and propagation of corrosion; the Clear equation was not included in the compilation. Therefore, NRC staff could not verify that the Clear empirical equation is a "broadly accepted methodology."

Path Forward

Additional information should be developed in support of the PA which:

1. Provides additional discussion on the empirical equation by Clear (1976) to estimate the initiation time of steel corrosion by chloride, including the range of conditions of validity of the equation such as concrete quality, chloride concentration, and time span, and examples of where that equation has been used in other systems;
2. Evaluates the appropriateness of using the empirical equation to model corrosion of steel liners, including the validity of extrapolation to long terms; and
3. Assesses the uncertainty in the initiation time, or justifies disregarding further consideration of the propagation of uncertainty.

Comment NF-11

In the PA, time-to-failure by corrosion is not calculated for tank configurations with fast water flow paths, in which infiltration water with relatively high oxygen concentrations and low pH is directly in contact with the steel liner. Therefore, it is not clear if failure time estimates apply to these tank configurations.

Basis

Section 4.4.2 of the PA presents six tank configurations (A through F). The model to derive times to carbon steel liner failure is based on the assumption that the transport of key species (carbon dioxide and oxygen) is controlled by diffusion (SRNL, 2008). In the case of depassivation by carbonation, the process that controls the time to failure is diffusion of carbon dioxide (CO_2). When depassivated by a drop in pH in the pore water in concrete or grout, carbon steel is assumed to corrode at a rate of 10 mils/year, with full penetration of the liner by the corrosion front taking a few decades (SRNL, 2008). On the other hand, in the case of chloride induced corrosion, the time to failure is controlled by the diffusion of chloride, and by the diffusion of oxygen after the steel is depassivated by chloride. The attack by chloride is assumed to take place in the form of general, uniform, corrosion. Localized corrosion, in the form of pitting corrosion, is assumed not to occur.

High values of the diffusion coefficient of CO_2 were considered to represent the fast flow paths in Tank Configurations C and D (Table 4.4-1 of the PA). For these configurations, it is not clear that the drop in pH of water in contact with steel is appropriately modeled as a CO_2 diffusion controlled process. Advection of CO_2 may cause a change in pH in a shorter period time than would be estimated by diffusion. It is not clear if the empirical equation to compute the time of initiation of corrosion by chloride applies to the case of fast water flow paths through concrete. A large supply of oxygen through advective means may increase the rate of corrosion induced by chloride.

For Tank Configurations B, C, D, E, and F, the analysis in the PA relies on an assumption that the cementitious materials are fully degraded after 501 years (page 382-387 of the PA). Further, for Configurations C, D, and E, it was assumed that concrete/grout pore water with relatively high oxygen concentration and low pH is in immediate contact with the steel liner since closure (page 383-386 of the PA). Under these conditions (cementitious materials fully degraded, or low pH and high O_2 concentration water in contact with the steel liner), it is not clear that the assumed chloride and oxygen diffusion mechanisms, which are assumed to control failure times of the liner, would operate.

Path Forward
The PA should:

1. Clarify the technical basis for modeling the drop in pH of the water in contact with the liner steel as a CO_2 diffusion controlled process for tank configurations C, D, and E (according to computations in SRNL, 2008), given that the PA (pp. 383-386) relies on an assumption that low pH water would be in direct contact with the steel liner;
2. For Tank Configurations C, D, and E, provide a technical basis for computing the time of corrosion initiation by chloride as an empirical equation that does not explicitly account for advection of the chloride ion (SRNL, 2008);
3. Provide a technical basis for modeling the rate of corrosion initiated by chloride as a process controlled by the diffusion of O_2 [according to computations in SRNL (2008)] for Tank Configurations B, C, D, E, and F. In the technical basis, analyze rates of transport associated with advection and diffusion of O_2, accounting for the effect of enhanced hydraulic conductivity after full degradation of concrete/grout; and
4. Provide a technical basis for disregarding pitting corrosion of carbon steel for all tank configurations.

Comment NF-12
The PA should describe how degradation processes that could affect the carbon steel, such as galvanic corrosion, microbial induced corrosion, stress corrosion cracking, pitting corrosion, and different corrosion resistance of welds, heat affected zones, and plates, were considered in the context of the different model tank configurations and degradation mechanisms affecting concrete and grout.

Basis
SRNL (2008) does not include an assessment of potential corrosion degradation processes affecting steel liners consistent with the model tank configurations and concrete and grout degradation mechanisms considered in the performance assessment model. For example, the argument that variability in corrosion rates due to galvanic corrosion may be disregarded is based on the assumption that quality of concrete and steel is uniform (SRNL, 2008, pages 28, 29). However, if fast flow paths are established there may be regions where ionic conductivities, concentrations, and pH in the water could differ from corresponding conditions in the pore water in concrete/grout. These differences may result in microcell/macrocell corrosion of the steel liner.

Microbially induced corrosion is disregarded in the PA on the basis that the formation of microorganisms is prevented by the alkalinity of pore water in concrete (SRNL, 2008, page 29). After carbonation, the assumed high corrosion rates of the steel are assumed to account for the potential for MIC (SRNL, 2008, page 29). As stated under Comment NF-11, the pH under high flow paths may be controlled by advection, rather than diffusion, and less alkaline solutions may be attained sooner than estimated in the diffusion model. The pH may also change as a result of concrete degradation. For Tank Configurations C, D, and E, the PA assumes that relatively low pH water is directly in contact with the steel liner.

SRNL (2008) estimates the initial crack opening area associated with stress corrosion cracking. It is implied that further stress corrosion cracking is unlikely for all of the model tank configurations. No discussion is provided to support this assumption.

The PA or its supporting reference (SRNL, 2008) should also address the potential different corrosion susceptibility of welds, heat affected zones, and plates.

The potential for pitting corrosion was not considered for those tank configurations with early degradation of cementitious materials (tank configurations B, C, D, E, and F), or with water of low pH and high O_2 concentration that is assumed to be directly in contact with the steel liner (i.e., tank configurations C, D, and E). If the chemistry of water flowing through the grout/concrete is similar to the water flowing through soils, it appears that carbon steel could undergo pitting corrosion.

Path Forward

The PA should contain screening arguments for inclusion or exclusion from further consideration additional corrosion processes that could affect carbon steel liners. Additional processes include galvanic corrosion, microbial induced corrosion, stress corrosion cracking, pitting corrosion, and different corrosion resistance of welds, heat affected zones, and plates. Also, the screening arguments in the PA should address various tank configurations and grout and concrete degradation mechanisms.

Comment NF-13

The PA should clarify how estimates of corrosion rates of the steel liner under humid air conditions were considered in the performance assessment model.

Basis

A scenario is considered in SRNL (2008), on page 39, in which a pipe of humid air is assumed to form between the grout/vault and the tank steel and cause humid air corrosion of the steel liner. Using data in support of the Yucca Mountain project, SRNL (2008) estimated lifetimes for the steel liner under humid conditions ranging from a few decades to a few hundreds of years (SRNL, 2008, Table 17). It is not clear how these estimates were used in the performance assessment model.

Path Forward

The PA should clarify how data in Table 17 of SRNL (2008) were considered in the performance assessment model. If those lifetime estimates were not used in the performance assessment model, provide a technical basis.

Comment NF-14

The PA describes how Type I Tanks 1, 5, and 6 have experienced stress corrosion cracking, which has resulted in leaks from the tanks and deposits of waste on the annulus floor. It is not clear how past experience with stress corrosion cracking is considered in the performance assessment model.

Basis

Type I Tanks 1, 5, and 6 have experienced stress corrosion cracking, resulting in deposits or waste accumulated on the annulus floor (SRNL, 2008, Section 2.2.2 and Table 7). The material in the annulus is expected to be dried salt that should be removable during cleaning (as described on page 213 of the PA). The crack opening area for stress corrosion cracks was estimated to be minimal (SRNL, 2008, page 19). There is no further discussion on how past experience with stress corrosion cracking was considered in the performance assessment model.

Path Forward
The PA should further explain how past experience with stress corrosion cracking is considered in the performance assessment model.

Comment NF-15
Section 4.2.2 of the PA should identify the computer code used for solubility calculations, and the thermodynamic database employed with the code.

Basis
While Section 4.2.2 of the PA does mention that Geochemist's Workbench was used for simulating geochemical conditions during grout degradation, the text does not state that the same code was used for radioelement solubility models. In addition, the particular thermodynamic data used in the geochemical and solubility models is not identified. The choice of thermodynamic data sources can strongly affect modeled solubility limits.

Path Forward
The PA should identify the specific computer code or codes used for geochemical and solubility models supporting the release model, and identify the specific thermodynamic database used in these models, as well as any specific modifications made to the database.

Comment NF-16
The PA should justify the selection of two end-member water chemical compositions for use in solubility modeling, and the exclusion of intermediate pH waters.

Basis
During degradation of cement-based materials, water chemistry passes through several stages that are best defined by pH. Much of this degradation history (e.g., Bradbury and Sarott, 1995) is characterized by pH between the two end-members—12.4 and 8.2—adopted by DOE in their solubility modeling. Neither portlandite nor calcite will be present over much of this time, during which the cement assemblage is characterized by calcium silicate hydrate (C-S-H) solids. It is not clear whether the DOE solubility models have potentially underestimated radionuclide release by abstracting chemical evolution as a two-step process from pH 12.4 to 8.2. Likewise, in the tanks, Eh may vary smoothly as the reducing capacity of the grout is exhausted.

Path Forward
The PA should provide a technical basis for confidence that the two-stage chemical model for establishing radionuclide release parameters—which neglects intermediate pH and Eh evolution—has not resulted in underestimating release rates from the grouted tanks.

Comment NF-17
The PA should explain the chemical conditions in the tests that measured K_d for cementitious materials.

Basis
Cementitious material K_d values for some radioelements – notably, Am, I, Np, Pa, U, and Tc (oxidizing conditions) - were based on sorption experiments reported in Kaplan and Coates (2007). The solid matrices in these experiments were fresh reducing grout, aged reducing grout, and aged concrete. Two solution types – $Ca(OH)_2$ equilibrated and $CaCO_3$ equilibrated – were used in the experiments. The applicability of the results to conditions modeled in the PA is not fully supported in the PA without data on the geochemistry (e.g., pH, Eh, and carbonate content) of the solutions during the sorption experiments.

Path Forward
The PA should provide data on the chemical compositions of solutions during the sorption experiments reported in Kaplan and Coates (2007).

Comment NF-18
The PA should explain why the 40 year-old concrete used in sorption experiments that form the basis for values for aged basemat is a sufficient analog for much older concrete that may be present in the basemat when radionuclides are released from the grouted tank.

Basis
As acknowledged on page 7 of Kaplan and Coates (2007), the solid phases making up the sampled concrete used in sorption experiments will not necessarily correspond to the constituents of much older concrete present in the basemat if radionuclides are released thousands of years after tank closure. Nevertheless, data from these experiments are used in the performance assessment for oxidizing conditions for Am, I, Np, Pa, Tc, and U. In particular, this approach results in non-zero recommended K_ds for I (Stage 3) and Tc (all stages), in contrast with the zero values earlier recommended in Kaplan (2006a).

Path Forward
The PA should provide the technical basis for the applicability of the Kaplan and Coates (2007) aged concrete sorption data throughout the modeled time period in the tank farm performance assessment.

Comment NF-19
Some of the reported standard deviations for K_d values for cementitious materials in Kaplan and Coates (2007) are high, suggesting that some measured values may have been considerably lower than the recommended values.

Basis
In Kaplan and Coates (2007), standard deviations are reported on sets of three measurements for K_d on cementitious materials. Many of the reported standard deviations are on the order of fifty-percent or more of the mean, with some exceeding the mean in magnitude. This suggests that some measured values could be much lower than the mean and, thus, the recommended value. This could lead to overpredicting the sorptive capabilities of cementitious materials in the system.

Path Forward
The PA should describe the individual sorption experiment results reported in Kaplan and Coates (2007) and provide the basis for adopting the mean values, where applicable, even when the minimum measurement was significantly lower than the mean.

Comment NF-20
The technical basis for Tc K_ds for cementitious materials under reducing conditions should be clarified in the PA or supporting references.

Basis
The reference for Tc K_d values for cementitious materials under reducing conditions in Table 4.2-33 of the PA is Kaplan (2006a), Table 14. The values adopted in the PA are 5,000 mL/g for each of the three ages of material. In the source table, Kaplan (2006a) states that these values are taken from Bradbury and Sarott (1995). Table 4 in Bradbury and Sarott (1995), however, recommends reducing conditions values of (1) 1,000 mL/g for Region I ("young age" in the performance assessment), (2) 1,000 mL/g for Region II ("middle age"), and (3) 100 mL/g for Region III ("old age").

Path Forward
In the PA, reconcile the adopted reducing conditions Tc K_ds for cementitious materials with the cited source or provide a technical basis for the adopted values of 5,000 mL/g.

Comment NF-21
In the PA, clarify the basis for using tank dip sample concentration measurements for establishing Tc and Se solubilities for release modeling.

Basis
In the PA, concentrations measured in the supernate from a dip sample from Tank 18 are used to estimate the solubility of (i) Se under oxidizing Region II and oxidizing Region III conditions and (ii) Tc under oxidizing Region III conditions (Table 4.2-10 of the PA). The adopted values are low, considering that most studies do not support solubility control for Tc (e.g., Krupka, et al., 2004) and Se under oxidizing conditions (e.g., Séby, et al., 2001; Berner, 2002).

The data source for the dip sample is presumably Swingle (2002), Table 4 (though that value for Tc-99 is about 50 percent higher than the value adopted for the PA in Table 4.2-10). The source document notes that the supernate was filtered before radionuclide analyses (Swingle 2002), page 4, whereas page 270 of the PA states that the Tank 18 sample was unfiltered. No supernate pH data were presented in Swingle (2002).

It is not clear from the available data that the concentrations of Tc-99 and Se-79 in the dip samples of supernate provide appropriate estimates of aqueous concentrations during interactions between percolating water and residual waste in grouted tanks. The geochemical characteristics of water contacting the residue in a breached grouted tank may be quite different from the analyzed Tank 18 supernate. In addition, the information presented in the PA does not provide a basis for assuming that the Tc-99 and Se-79 contents of the Tank 18 supernate are at a concentration limit. The Tc and Se in the Tank 18 solid residue at the time of sampling may not have been in equilibrium with dissolved Tc and Se and may, for example, reflect the particular circumstances of the quantity of liquid and timing and nature of interaction between residue and liquid in Tank 18 prior to sampling.

Path Forward
DOE should confirm the source of the Tank 18 dip sample supernate data used to support the Tc and Se solubility values in Table 4.2-10 of the PA and explain: (1) the apparent 50 percent discrepancy in Tc-99 values between Swingle (2002) and WSRC (2008), and; (2) whether the Tank 18 liquid sample was filtered before radioanalysis. Additional information should be obtained and reported in the PA on the pH of the sampled Tank 18 supernate. The PA should also describe why it is reasonable or bounding, in light of the comments above, to assume that the Tank 18 supernate Tc-99 and Se-79 concentrations provide estimates of concentrations in a water percolating through the residue in a grouted F-Area tank. These arguments should

specifically address oxidizing Region II and III conditions for Se and oxidizing Region III conditions for Tc.

Comment NF-22

The PA should more clearly describe the basis for the Fe coprecipitation model used for establishing Tc and U solubilities for release modeling.

Basis

DOE uses a model of coprecipitation with Fe oxides for establishing Tc and U solubilities under reducing Region II and oxidizing Region II conditions (Tables 4.2-10 and 4.2-18 of the PA). This approach results in markedly low Tc-99 concentrations of $\leq 3\text{x}10^{-11}$ M, particularly considering that most studies do not support solubility control for Tc under oxidizing conditions (e.g., Krupka, et al., 2004). In addition, calculated U solubilities of $\leq 2\text{x}10^{-9}$ M are low compared to most estimates under relevant conditions (e.g., Ewart, et al., 1992; Krupka and Serne, 1998; Pointeau, et al., 2004).

The Tc coprecipitation model (Denham, 2007, pages 14-16) is best supported by a cited study by Cantrell, et al. (2006), which suggested that the insoluble fraction of Tc in Hanford tank residue sludges is associated with iron hydroxide, resulting in release concentrations of $\leq 10^{-11}$ M. That study, however, also included data on a much more soluble Tc fraction from the residues. Cantrell, et al. (2006) also reported data on soluble and insoluble U fractions that both yielded release concentrations well in excess of the solubilities used in the PA. The PA does not cite the Cantrell, et al. (2006) U results. In addition, the Cantrell, et al. (2006) sequential extraction experiments were not directed toward cementitious systems and were not conducted with extractants similar to what would be present under Region II conditions.

The PA does not show that the soluble Tc and U fractions will have been removed from all tank residue before closure. In addition, the PA has no discussion of why the same Fe coprecipitation process would have occurred in SRS tanks. If more soluble Tc and U fractions are not removed during tank cleaning, or if Tc and U are not demonstrably coprecipitated with Fe oxides/hydroxides in SRS tanks, Tc and U release concentrations could be much higher than predicted by the Fe coprecipitation model.

Path Forward

The PA should provide more support to the Tc and U Fe coprecipitation models by providing a technical basis that: (1) Tc coprecipitation with Fe oxides/hydroxides observed in two Hanford tank sludges will also apply in grouted SRS tanks (Region II conditions); (2) little or no more-soluble Tc fraction will remain in grouted SRS tanks, and; (3) U will be coprecipitated with Fe oxides/hydroxides in SRS tank sludges, rather than occurring in the more soluble U phases identified by Cantrell, et al. (2006) at Hanford. In addition, the PA should explain why the Fe coprecipitation model applies only to Region II conditions.

Comment NF-23

The PA should provide a technical basis for the distribution coefficient and Fe phases used for calculating Tc, U, and Pu concentrations in the Fe coprecipitation model.

Basis

In the PA, DOE uses a model of coprecipitation with Fe oxides for establishing Tc, U, and Pu solubilities under reducing Region II and oxidizing Region II conditions (Tables 4.2-10 and 4.2-18 of the PA). For each element, the calculated solubilities are orders of magnitude lower than ranges of pure-phase solubilities suggested by the literature and modeling (e.g., Krupka, et al., 2004; Krupka and Serne, 1998; Neck, et al., 2007). The PA describes assumptions of ideal behavior and a distribution coefficient of 1 that were used to calculate the radioelement concentration as a function of Fe solid phase solubility. In the model, therefore, the ratio of Tc, U, or Pu to Fe in solution is the same as in the solid Fe oxide, and the Fe in solution is controlled by the solubility of Fe oxides magnetite (reducing conditions) or hematite (oxidizing conditions [Denham, 2007, page 16]). (The higher solubility of magnetite versus hematite is likely to be the reason the calculated Tc, U, and Pu concentrations are lower under oxidizing conditions, counter to typical observations for these redox-sensitive elements.)

The PA does not, however, provide a technical basis for the distribution coefficient of 1 used for Tc, U, and Pu. In addition, the PA does not provide the basis for using Fe oxides in the model, rather than potentially more soluble Fe hydroxides or oxyhydroxides (e.g., ferrihydrite versus hematite). Some of the sources cited in the Denham (2007) discussion of Fe coprecipitation (e.g., Cantrell, et al., 2006) specifically referred to Fe hydroxides.

Path Forward

For the Fe coprecipitation model described in the PA, provide a technical basis for: (1) the use of a distribution coefficient of 1 for Tc, U, and Pu, and; (2) calculating Fe phase solubilities using magnetite and hematite.

Comment NF-24

The PA should explain how the process model used to estimate the time to chemical transition in the contaminated zone adequately represents physical changes in the cementitious material that could affect chemical transitions.

Basis

Section 4.2.2.6 of the PA describes how a geochemical analysis was performed to estimate the evolution of the pore water chemistry. Evolution of the pore water chemistry in the grout was modeled using *The Geochemist's Workbench*. The analysis simulates thermodynamic chemical reactions between pore water species and grout mineralogy resulting in the estimated evolution over time of pH and Eh. The process model assumes that the entire grout mineralogy is available to react with the spectrum of pore water species. If a portion of the mineralogy is not available at the interface to react with pore water constituents, the evolution of the pore water chemistry may be different than that described by the geochemical analysis. For instance, water traveling through a network of cracks in any of the tank configurations will likely only contact a limited mass of the grout mineralogy, possibly exhausting the buffering capacity along these cracks much more rapidly than in porous media flow pathways. Assuming a prolonged delay in the time to chemical transition for tank configurations A, B, E, and F that are not assumed to contain fast pathways, may not be fully supported. Additionally, as the grout minerals are dissolved from their matrix by the pore water, physical evolution of its properties may be expected including changes in porosity, hydraulic conductivity, and associated mass with time. As the pore volume changes, the buffering capacity of the mineralogy might be expected to deplete more rapidly due to a potential increased mass of pore water constituents. However, the analysis performed using *The Geochemist's Workbench* does not appear to consider physical changes in porosity or hydraulic conductivity or the effect of available surface mineralogy on the evolution of pore water chemistry.

The PA states on page 325 that the transition times between chemical states was varied stochastically, as described in Section 5.6.3.8 of the PA. However, a basis for the distribution is not provided. If the distribution used for the chemical transition times (pore volumes) is tied to the error that may result from decoupling the chemical and physical degradation models, this should be documented.

Path Forward
The PA should demonstrate that the analysis to estimate chemical transition times is reasonable, given that the conceptual model for chemical and physical degradation of the grout are de-coupled and may not consider mechanisms occurring in the real system that could decrease the time to chemical failure for tank configurations where chemical transitions are not assumed to be instantaneous (e.g., Configurations A, B, E, and F). DOE could assess the uncertainty in the conceptual model for chemical transition by developing a distribution for the potential chemical transition times that appropriately considers physical changes in the tank grout.

Comment NF-25

The PA should provide a more transparent description of the PORFLOW flow model abstraction in GoldSim. Features of the disposal facility important to the hydraulic performance of engineered barriers should be evaluated and fully supported to increase confidence in the performance assessment predictions.

Basis
As waste release has a significant impact on the results of the performance assessment calculations, the abstraction of the waste release model (i.e., two-dimensional PORFLOW to one-dimensional GoldSim flow for Configurations A-F) and implementation of this abstracted waste release model in GoldSim should be clearly documented and supported. Parameters and processes represented in the more complex PORFLOW model are lumped together into single parameter values (i.e., flow velocities) for use in GoldSim. Therefore, the sensitivity of performance assessment results to changes in these parameters and processes (e.g., time variant hydraulic conductivities, diffusivities, saturation, and infiltration rates) that are represented in the more complex and deterministic PORFLOW model are not directly evaluated by the probabilistic analysis in GoldSim.

Additionally, as modeled in the PA, it is not clear what impact the absence of a top liner for Type IV tanks has on flow and transport prior to steel liner failure. It is also not clear what impact, if any, the diffusion of waste residuals into the tank grout has, for all tank types, on: The distribution of contamination, and; release of waste after the steel liner fails. Finally, it is not clear if advective flow through the tank grout has an impact on chemical conditioning of pore water passing through the contaminated zone. The PA should clearly describe and evaluate the risk significance of these parameters and processes. Commensurate with the risk significance of these parameters and processes, additional support may be needed to provide confidence in the performance assessment results.

The PA should address the following specific issues related to the flow velocities that were calculated for use in GoldSim:

1. It is not clear why the velocities for Configurations C and D are the same for all tanks when no fast flow path through the basemat exists in Configuration C (Figures 5.6-16 and 5.6-17 of the PA);
2. It is not clear why the flow rates for Type IV tanks are much lower than Type I tanks for Configurations C and D when the cementitious materials are all assumed to fail after 500 years. The PA should clarify whether the representation of the fast pathway or

discretization of the tanks is the cause for the significant differences in the flow velocities for the different tank types in Figures 5.6-16 and 5.6-17.

3. It is not clear why the velocities in Configuration E (Figure 5.6-18) are much higher for Type III/IIIA tanks compared to Type IV tanks. As configuration E represents a configuration where the water table rises above the bottom of the tank, it is not clear why a velocity profile for flow through the system is provided (i.e., the PA should clarify which flow vector this profile represents, since there is only saturated zone flow through the contaminated zone).
4. It is not clear why there is generally a non-zero flow rate for all tank types except Type IV prior to steel liner failure when Type IV tanks are the only tanks without a top liner and could experience flow prior to steel liner failure (Figures 5.6-14 through 5.6-19).
5. The PA should explain why the flow velocities are higher than the infiltration rate for all tank types in Configuration F (Figure 5.6-19).
6. It is not clear what fraction of infiltration is conducted through the fast pathways simulated in Configurations C and D (compared to what fraction is conducted through the porous grout monolith) for all tank types following steel liner failure. The PA should clarify whether the hydraulic properties of the grout monolith are assumed to be (1) in-tact as in Condition 2 (see Figure 4.2-1) or (2) partially degraded at the time of steel liner failure as indicated on the timelines presented in Table 4.4-3. The PA should also clarify what impact, if any, the hydraulic property assumptions have on the estimated flow velocities and on waste release (e.g., does flow through the degraded grout monolith affect the chemistry in the contaminated zone).

Path Forward

The PA should contain additional information regarding the abstraction of the flow model from two-dimensional to one-dimensional flow, including details on what the flow velocities in Figures 5.6-14 through 5.6-19 represent. The PA should discuss unexplained results presented in Figures 5.6-14 through 5.6-19 related to flow through the engineered barrier described above. The PA should also clarify whether flow through degraded grout in Configurations C and D affects the chemistry in the contaminated zone.

The PA should discuss what impact, if any, the absence of a steel liner top for Type IV tanks and diffusion in the waste form for all tank types has on flow and transport, and waste release.

To the extent that cap performance (Configurations A-E), assumed hydraulic properties of cementitious materials (Configuration A), and tank design affect the flow velocities through the system, these attributes of the disposal facility should be evaluated and discussed to provide context for the features of the system most affecting performance.

The PA should also assess the significance of lumped parameters (e.g., hydraulic conductivity, effective diffusivity, saturation, and infiltration) on the results of the performance assessment. Commensurate with the risk significance of these parameter values, provide adequate support for the values selected for the deterministic analysis and justification for the treatment of these parameters in the probabilistic analysis to increase confidence in the performance assessment results.

Comment NF-26

The PA should more transparently describe how the hydraulic and chemical transitions are derived.

Basis

Section 4.2.2.6 of the PA describes the methodology used to estimate a relationship between infiltrate pore volumes and chemical degradation of the waste tank grout. Denham (2007) describes the analyses used to estimate the chemical degradation transitions (i.e., Eh and pH) as a function of infiltrate pore volumes through the waste tank grout. Tables 4.4-2 through 4.4-5 of the PA describe the time evolution of parameters including chemical degradation transitions for the waste tank types for Configurations A and D. The tables indicate transition times for both the waste tank grout and contaminated zone. Occasionally, the chemical transition times listed in the tables are the same (e.g., Configuration A) for the waste tank grout and contaminated zone while in other instances they are different (e.g., Configuration D). This appears contradictory to the description in section 4.2.2.6 of the PA and Denham (2007). It is not clear from the tables whether waste tank grout or contaminated zone chemical degradation is used to control chemical conditions (e.g., solubility and K_ds) for the release of waste from the tanks. It is also not clear whether the waste tank grout transitions are for the entire tank mass of grout or the mass contacting infiltrate in the fast flow path K_d

Path Forward

The PA should provide a more transparent description of the determination of the evolution of hydraulic and chemical transitions affecting radionuclide release with time. A more transparent description could include for each configuration whether the estimate of infiltrate pore volumes is performed dynamically within a PORFLOW or GoldSim simulation or externally to these simulations and calculations; parameter values associated with the estimation of transition times; and coupling between hydraulic and chemical degradation transitions.

Clarifying Comments—Near Field

Clarifying Comment NF-27

Section 5.6.2.3 of the PA describes the initial benchmarking efforts that identified inconsistencies between the GoldSim and PORFLOW models. This section discusses an alteration of the solubility of protactinium in water from infinitely soluble to a low solubility (i.e., 10^{-12} mol/L) to attain alignment of the water fluxes between the models. The rationale for this change was to account for the manner in which solubility is treated in PORFLOW. The PA should clarify further how PORFLOW handles solubility, in which models changes were made, and why this change was necessary.

Clarifying Comment NF-28

Section 5.6.6.3 of the PA discusses the important variables for particular endpoints. In most cases, the K_d of the basemat is not one of the top four important variables. The K_d for Th in oxidizing young concrete is an important variable for the maximum chronic inadvertent human intruder dose in 10,000 years (p. 617 of the PA). This result conflicts with the statement on page 325 of the PA that Region I (young) is not used to characterize any of the cementitious materials. Either this is a typo and it is meant to refer to the K_d for Th in middle age concrete, or the basemat is actually characterized as Region I initially. The partial dependence plot shows that if the K_d is low, the dose is much greater (around 1,400 mrem/yr). The PA should clarify whether this K_d is an important variable for this endpoint. If the young value was used, the PA should so state and explain the reason. Alternatively, the PA could explain what the important variable actually is if it is not the young K_d.

Far-Field Comments

In the PA, DOE uses a far-field model to simulate the flow and transport of radiological constituents from the point of release outside the engineered tank system through the environment to various points of exposure where a receptor might be exposed. PORFLOW is used to simulate flow and transport in the far-field environment for the compliance case, i.e., Configuration A. PORFLOW is also used to simulate *flow only* for all other Tank Configurations. Far-field *transport* modeling is implemented in GoldSim for all tank configurations in the probabilistic analysis. Because GoldSim does not solve flow equations, flow velocities were calculated for use in GoldSim using PORFLOW model results. Risk-significant aspects of far-field modeling include assignment of natural system K_ds (e.g., clay lens in vadose and saturated zone) that impact the timing and magnitude of doses for key radionuclides and factors that influence groundwater dilution (e.g., groundwater flow velocities and aquifer thickness). Thus, most of the following comments are related to K_d, groundwater dilution, and aquifer thickness parameter assignments and distributions used in the probabilistic analysis. Other comments are related to calibration of the PORFLOW model to provide confidence in the modeling predictions, and benchmarking of GoldSim with the PORFLOW model.

To develop the following comments, staff reviewed the PA and supporting documents provided to NRC by letter dated August 20, 2008 (Spears, 2008). The staff's review criteria pertaining to far-field radionuclide transport are contained in sections 4.2, 4.3.4, 4.4, and 4.6 of NUREG-1854, "NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations" (NRC, 2007).

Comment FF-1

Technical reports cited in Section 5.6.3.4 of the PA on which the K_d distributions used in the PA are based contain an error and some ambiguity.

Basis

K_d distributions cited in the PA are based on Shine (2007), which tests the goodness of fit for data from 20 soil samples to normal or lognormal distributions for Cs, Sr and U. Shine (2007) appears to have an error and some ambiguity:

- The discussion in the body of Shine (2007) does not match the figures. The body discusses removal of data point 31A, whereas the figures show that 19A was removed as an outlier;
- Bounds are placed on the lognormal distributions for K_d values in the PA by multiplying or dividing the expected value by 3.3 if it is greater than 1,000 mL/g or 1.9 if it is less than 1,000 mL/g. However, it is not clear how the data in Shine (2007) supports this method for bounding the distribution.
- It is not clear how the lognormal distribution parameters were determined for radionuclides other than Cs, Sr, and U.

Path Forward

The PA should clarify the ambiguities in the reference paper mentioned above. In addition, NRC staff recommends comparing the distributions that are used applying this method for radionuclides other than Cs, Sr, and U with those for clayey or sandy soil K_ds in the literature to support the approach used. If this comparison indicates PA distributions that are very different from literature values, provide the justification for using site-specific data in this reference for all radionuclides.

Comment FF-2
Development of vadose zone transport parameters in the PA should consider the geochemical environment below a large body of cement-based materials.

Basis
As water exits the base of a tank, it will bear the geochemical imprints of interaction with cement-based materials (e.g., elevated pH), depending on the degradation state of the material. This geochemical character may affect the sorption behavior of radionuclides transported in the water. The technical bases for vadose zone K_d values used in the PA do not explicitly consider the potential effects of this impact on water chemistry.

Path Forward
Explain the appropriateness of selected K_d values for the vadose zone in light of the potential range of geochemical characteristics of waters exiting tanks filled with cement-based materials.

Comment FF-3
The PA does not provide information regarding a plan for F-Area stormwater retention/seepage basin decommissioning. If decommissioning is not planned, or if plans for F-Area manmade surface water facilities are currently undeveloped, the PA should provide information about assumptions DOE made in the absence of such plans. Furthermore, additional information and analyses should be provided in the PA to justify the erosion protection design for the south side of the closure cap near the stormwater retention/seepage basins.

Basis
The F-Area stormwater retention/seepage basins are significant surface water bodies in the vicinity of the F-Tank Farm (page 300 of the PA) that currently affect the far-field hydrologic flow and transport system at this site. If stormwater retention/seepage basins will be present during part or all of the post-institutional control period, their presence should be accounted for in the far-field hydrologic flow and transport modeling.

In regard to the closure cap, while the NRC staff recognize that DOE has not finalized the erosion protection design on the south side of the closure cap near the stormwater retention/seepage basins (241-97F Cooling Water Basin and 281-8F Basin), the erosion protection design in this area may be important in the evaluation of the overall closure cap performance. The PA states that conservative assumptions were made in selecting the designs; however, based on review of this area of the closure cap, this case has not been clearly made.

Path Forward
The PA should provide information regarding planned decommissioning activities of stormwater retention/seepage basins at the F-Area, including the timing of such activities as it relates to the anticipated initiation of the post-institutional control period for the F-Tank Farm. If plans for the F-Area manmade surface water facilities have not yet been developed, the PA should state the assumptions made in the absence of such plans, and provide information to support these assumptions. The PA should also contain further information and analyses to show that the currently-proposed design is capable of protecting the closure cap from erosion and gully intrusion on the south side of the cap. For example, if the basins are filled, different toe configurations and/or diversion channels could be used; if the basins are not filled, the side slopes of the basins could be stabilized with riprap.

Comment FF-4
Potentiometric surface maps provided in the PA are often ambiguous due to issues of scale and lack of local context markings. Potentiometric surface maps with higher resolution than the local General Separations Area (GSA) scale are needed for communicating the local flow regimes of direct relevance to the F-Tank Farm. Figures 3.1-16 (page 79) and 3.1-17 (page 80) of the PA illustrate potentiometric surfaces at the very low resolution of the entire Savannah River Site and do not include an outline of the GSA or any other means to clearly place the F-Tank Farm facility in context with respect to its local potentiometric surfaces for the relevant aquifers. While Figure 4.2-16 is helpful for communicating the local water table aquifer heads, this figure does not include an outline of facility locations for context, nor is there an equivalent figure for communicating the flow field in the Gordon Aquifer at depth. While Figure 4.2-17(a)(b) is helpful for comparing GSA/PORFLOW model-predicted water table heads with measured data and the figure properly shows facility locations for context, the two maps shown in this figure are oriented at different angles, making direct comparisons more difficult, and there is no equivalent figure for comparing GSA/PORFLOW model-predicted hydraulic heads in the Gordon Aquifer at depth with measured data. It is likely that the hydraulic heads in the upper zone (UZ) and lower zone (LZ) of the water table aquifer (UTR) are somewhat different if the Tan Clay is operating as a semi-confining zone, but the PA does not identify its UTR potentiometric surface maps as belonging to one zone or the other, leading to additional ambiguity.

Basis
Potentiometric maps can be an effective means of communicating data for local flow and contaminant transport behavior. The GSA/PORFLOW model was calibrated and validated using measured well water levels (page 299 of the PA)—the same data that is used to create potentiometric maps. The PA states that GSA/PORFLOW model-predicted hydraulic heads agree with potentiometric maps based on measured hydraulic heads (page 300 of the PA). Data should be provided that supports this statement for all relevant aquifer zones.

Path Forward
The PA should contain higher-resolution, F-Area-scale potentiometric surface maps for the Upper Three Runs and Gordon Aquifers, because this scale is most relevant to the F-Tank Farm and far-field transport of contaminants to the anticipated receptor. If there are any differences in hydraulic heads between the UTR-UZ and UTR-LZ, provide this detail in potentiometric surface maps. Provide a comparison between GSA/PORFLOW model-predicted hydraulic heads in the Gordon Aquifer and measured Gordon Aquifer hydraulic heads. Orient maps consistently to aid interpretation and evaluation of results.

Comment FF-5
Information used to “validate” PORFLOW modeling results in the PA is ambiguous and does not appear to support conclusions regarding the adequacy of the model in simulating important contaminant flow and transport processes in the subsurface.

Basis
Adequate calibration of the PORFLOW model is important to demonstrating that the performance assessment model is capable of making accurate dose predictions for the purposes of demonstrating compliance with performance objectives. In a subsection on Vadose and Aquifer Model Validation in PORFLOW (starting on page 419 of the PA), the PA attempts to demonstrate that a “similar” PORFLOW vadose zone model predicted tritium concentrations that are consistent with tritium concentration data to provide support for the model; the PA cites Figure 4.4-36 to make this case. Because Figure 4.4-36 lacks sufficient explanation and because PORFLOW apparently under-predicts tritium edge concentrations, this figure does not

fully support DOE's analysis. Figure 4.4-36, which was used to demonstrate the validation of a "similar" PORFLOW vadose zone model, is ambiguous due to lack of sufficient explanation, and remains unconvincing because of edge concentrations that are under-predicted by PORFLOW. In particular, the red graphs are labeled "Generic" without explanation of what "Generic" means in this context, and the blue graphs are labeled "Concrete" without explanation of what "Concrete" means in this context. The blue graphs for "Concrete" are under-predicting edge concentrations that may represent differences in flow and transport in the vadose zone (e.g., the data may indicate significant lateral flow).

Comparisons of measured plume concentrations in the GSA with PORFLOW modeling predictions (Figures 4.4-38 and 4.4-39) is also used to partially illustrate that the model is well calibrated. However, details regarding the basis for the interpretation of the plume distributions (e.g., modeled or hand contoured) and conditions that led to the plumes (e.g., source locations and areas) was not provided making it difficult to judge the goodness of fit of the model to data.

Path Forward
The PA should provide sufficient explanation for what "Generic" (red graphs) and "Concrete" (blue graphs) labels refer to in Figure 4.4-36 and why the PORFLOW vadose zone model under-predicts edge concentrations, which may be related to lateral flow in the vadose zone. the PA should also provide more detailed information and references regarding past releases at the GSA and calibration of the PORFLOW models to this data.

Comment FF-6
Figure 4.4-37 of the PA should have a legend.

Basis
In a subsection on Vadose and Aquifer Model Validation in PORFLOW (starting on page 419 of the PA), DOE attempts to demonstrate that the GSA/PORFLOW model predictions of seeplines bordering the GSA have been compared to field observations with consistent results; The PA cites Figure 4.4-37 to make this point. Because Figure 4.4-37 lacks a legend, this figure does not fully support DOE's analysis.

Path Forward
Provide a legend for Figure 4.4-37 of the PA that will clarify how GSA/PORFLOW model predictions of seeplines bordering the GSA are consistent with field observations of seeplines. Also, address any discrepancies in model results that are inconsistent with field observations.

Comment FF-7
The maximum groundwater concentrations at 100 m are not clearly supported in the PA, due to the manner by which such computations, including assumptions, are handled.

Basis
The maximum dose location at 100 m from the F-Tank Farm is based on an analysis of a continuous source release for a single constituent (Figures 5.2-3 and 5.2-4 of the PA), which is not the case for the SRS F-Tank Farm. There would be multiple tank failures staggered in time throughout the post-institutional control period. There are multiple key radionuclides with varying transport rates. There would be affected groundwater flowing through the system in three aquifer zones located at different distances (vertical and lateral) from the 100 m buffer area. Identifying the point of maximum exposure may be a significantly more complicated process than envisioned in the PA analysis. The utility of Figures 5.2-3 and 5.2-4 are limited because the reader does not know the depth and aquifer through which the map in Figure 5.2-3

cuts or the instant in time that the map and Figure 5.2-4 cross-section represent. Vertical and lateral dimensions are missing from both the map and cross-section. Thus, it is not clear where the maximum UTR-LA and GA concentrations are located with respect to the 100 m buffer, given vertical gradients. The realistic evolution of the contaminant transport plumes in relation to the expected timing of source release and the location of the point of maximum exposure, whether at 100 m or further from the F-Tank Farm than 100 m need to be supported by the PA.

Path Forward
The PA should include an evaluation of alternative release scenarios for the realistic evolution of the contaminant transport plumes in relation to the expected time and discrete locations of source releases and the location of the point of maximum exposure. The PA should provide support for the assumption that the 100 m distance from the F-Tank Farm is the most appropriate distance for computing maximum dose in each of the three relevant aquifer zones. If Figures 5.2-3 and 5.2-4 continue to be relied upon to support the 100 m assumption, the PA should provide supporting information such as: (1) vertical and lateral dimensions, (2) higher-resolution insets with dimensions for illustrating plume details that are most relevant to the 100 m buffer area, (3) an indication of the depth/aquifer through which the map-view cuts, (4) associated map-view cuts of the other two aquifers that are not now shown, and (5) an indication of what the far-field black dots/nodes are meant to represent in Figure 5.2-3. Alternatively, DOE could justify why the assumption regarding the point of exposure being located at 100 meters for the three aquifer zones is reasonable or conservative.

Comment FF-8
The PA should more fully support the assumptions for lateral continuity and vertical thickness of the Tan and Green Clay aquitards in the F-Area (Page 299, 302, and 590 of the PA).

Basis
Aquitards separating the UTR-UZ from the UTR-LZ, and separating the UTR-LZ from the GA play a significant role in retarding radionuclide transport and in limiting the spread of contamination to lower aquifer zones. An EIS (DOE/EIS-0303, 2002) states that where present, the Tan Clay forms a semi-confining zone (‘aquitard’) separating the two zones of the Upper Three Runs aquifer, implying that the Tan Clay is not always present. The PA states that the Tan Clay is a relatively ineffective flow barrier (page 590). The same EIS states that the Green Clay aquitard (that separates the Gordon aquifer from the overlying Upper Three Runs aquifer) is not continuous and is known to pinch out in numerous locations, also implying that the Green Clay is not always present, even though the PA indicates the Green Clay is a very effective aquitard (page 590). Savannah River Site workers studying hydrologic variability in this part of the site have shown that the presence of small-scale features (e.g., common lenticular units and pinch-outs) can only be determined in this coastal plain subsurface environment using test spacings of approximately 20 m or less (Wyatt, et al., 2005). It is unclear if enough stratigraphic picks directly relevant to F-Area hydrology have been evaluated to ensure the widespread thickness and continuity of these semi-confining or aquitard layers as modeled in PORFLOW.

Path Forward
The PA should either: (1) Demonstrate that the component of the PORFLOW model that represents the Tan and Green Clays as laterally continuous and as having finite thickness is supported by sufficient local stratigraphic data; or (2) evaluate alternative scenarios for situations where the presumed aquitards are not fully effective in retarding radionuclide transport and in limiting the spread of contamination to lower aquifer zones.

Comment FF-9
The PA should provide information regarding the number of cells and cell dimensions used in the GoldSim far-field model (pages 428 and 429 of the PA).

Basis
GoldSim model construction has a very significant impact on the predicted doses. The sensitivity analysis in the PA states that the cross-sectional area of the saturated zone flow tube for the GoldSim model is said to be one of the most important parameters affecting dose. The PA should provide additional detail regarding the cross-sectional area of the flow tube in GoldSim, commensurate with its risk significance.

Path Forward
The PA should contain information about the number of cells and cell dimensions used in the GoldSim combined vadose and saturated zone far-field model.

Comment FF-10
The PA should provide objective evidence to support the assumption that PORFLOW numerical dispersion is at an acceptable level, given the importance of the PORFLOW modeling results.

Basis
Excessive numerical dispersion can lead to risk dilution. Numerical dispersion occurs both in the GoldSim one-dimensional model and in the PORFLOW three-dimensional model (page 558 of the PA). The PA does not address whether excessive numerical dispersion occurs in the PORFLOW model, but rather implies, without further support, that the PORFLOW numerical dispersion is acceptable.

Path Forward
The PA should provide additional information to support the adequacy of the PORFLOW modeling results for use in estimating peak dose to a member of the public (e.g., indicate the acceptability of numerical error inherent in the modeling results).

Comment FF-11
The PA should more clearly describe the GoldSim benchmarking process and rationale for any changes made, and the methods for updating the models. The actions taken to benchmark the GoldSim transport model to the PORFLOW transport model should be transparent.

Basis
The benchmarking process is what allows DOE to transition with confidence from highly detailed, three-dimensional, deterministic process modeling to simplified stochastic system modeling. However, insufficient information is provided in the PA on this process.

The PA states that the PORFLOW model bulk density was adjusted to account for the removal of clay lens masses (page 557), but does not explain why this was necessary or appropriate, and it remains unclear whether this action was taken as part of the benchmarking process or whether the benchmarking process simply consisted of the GoldSim adjustment to be consistent with this PORFLOW action. While clay lens masses were removed from PORFLOW, clayey soil was added to the GoldSim model as a calibration parameter (page 558), but the PA is not clear about how sandy and clayey soil properties were assigned to GoldSim cells. The number of mixing cells was increased in GoldSim to more closely match the PORFLOW discretization scheme (page 559), but the initial and final benchmarked numbers of mixing cells in the GoldSim transport model were not provided in the PA. Numerical dispersion should reduce the concentration of radionuclides, but Figure 5.6-1 (illustrating the differences between PORFLOW and GoldSim results prior to benchmarking) and the PA text suggest that GoldSim numerical dispersion actually increased the concentration of radionuclides by 1 to 4 orders of magnitude relative to the concentrations predicted by PORFLOW prior to benchmarking—an unexplained result. The PA indicates that the GoldSim plume function is an analytical plume spreading solution based on factors based on literature values, but a reference to the literature is not provided (page 561). Peak concentrations were adjusted during benchmarking by applying a "benchmarking factor" to the plume function (page 561), but the PA is not clear about the type of site-specific data (radionuclide? tank?) for which the benchmarking factors are a function. Figure 5.6-2 shows benchmarked Tank 1 results out to 20,000 years for four radionuclides and progeny (page 562), but benchmarking results out to peak dose might have been more appropriate.

Path Forward

The PA should clearly describe the GoldSim benchmarking process and rationale for the changes made and methods for making these changes.

Comment FF-12

Although "relative" information is provided related to the thickness of the various aquifer zones in the PA (e.g., page 299), the PA does not provide in either Figure 4.2-13 or related figures the thickness of the PORFLOW modeled hydrostratigraphic units because a length scale is not provided. This issue is not addressed elsewhere in the PA. The minimum and maximum saturated zone thickness for the UTR-UZ should be supported, and if supporting references do not directly support the selection of a base case value of 5 m with variation up to 20 m for the UTR-UZ in the near vicinity of the F-Tank Farm, the PA should provide support for these GoldSim model assumptions.

Basis

Contaminants are assumed to mix throughout the total thickness of the aquifer. The basis for this assumption is not clear. The PA should provide support for the assumed aquifer thickness. Aquifer dilution is one of the most important factors affecting peak dose, according to sensitivity results provided in the PA (page 597).

Path Forward

The PA should provide a basis for the assumption that contaminants are mixed throughout the total thickness of the aquifer. The PA should also: (1) Provide a supporting reference for the selection of a base case UTR-UZ aquifer thickness value of 5 m, with variation up to 20 m in the near vicinity of the F-Tank Farm, and (2) provide additional information to support the approach used to consider uncertainty and variability in aquifer thickness for the UTR-UZ, UTR-LZ, and GA in the GoldSim model abstraction that only considers a single aquifer and demonstrate that the approach used is reasonable for the PA calculations.

Comment FF-13

The PA states that the Darcy Velocity has waste tank dependent base case values (page 597), but it is not clear why this should be the case. Also, the waste tank dependent base case values of 25 ft/yr or 30 ft/yr are not directly supported in the PA with data or references to other reports. The PA also does not state which base case velocity applies to which tanks.

Basis

The Darcy Velocity is an important GoldSim model parameter because it directly affects concentration.

Path Forward
The PA should provide support for the assumption that the GoldSim Darcy Velocity is waste tank dependent; provide information on which Darcy Velocity applies to which tanks, and provide support for the two assumed Darcy Velocities.

Clarifying Comments—Far-Field

Clarifying Comment FF-14

K_ds are not explicitly identified for saturated zone transport in Section 4.2.3.2 of the PA.

Basis
It is stated on page 337 of the DOE PA:

> Within the GSAD, soils with a saturated hydraulic conductivity greater than 1.0E-07 cm/sec are defined as sandy and those with a saturated hydraulic conductivity less than 1.0E-07 cm/sec are defined as clay for the purpose of defining transport properties (i.e., K_d and D_e).

This suggests that, for the saturated zone, sandy sediments are assigned the “vadose zone” K_d values from Table 4.2-29 and clay sediments are assigned the “backfill soil” K_d values from Table 4.2-29 (see footnotes 4 and 5 to Table 4.2-29). Staff was not able to confirm this inference.

Path Forward
The PA should include the K_d values for saturated zone transport, or confirm the staff inference that the data are in Table 4.2-29 as discussed above.

Clarifying Comment FF-15

The technical basis for the adopted Np and Pa K_d for clayey sediment is not apparent.

Basis
The K_d value for Np and Pa for clayey sediment (also used for backfill soil) is supported by Table 10 in Kaplan (2006a). That table, however, does not provide the basis for the “best” recommended value of 35 mL/g, which was adopted for the tank farm PA (Table 4.2-29 of the PA).

Path Forward
The PA should provide the technical basis for the Np and Pa K_d value of 35 mL/g that was adopted for clayey sediment.

Clarifying Comment FF-16

Cited information in support of sediment K_d values for Tc suggests that zero sorption is a reasonable and realistic assumption particularly for sandy sediments.

Basis
Tc K_d values of 0.1 and 0.2 mL/g are adopted in the PA for sandy and clayey sediment, respectively (Table 4.2-29 of the PA). The cited reference supporting these values—Kaplan (2006a), Table 10—presents data showing either limited or no sorption of Tc or analogous Re on SRS sediments.

Path Forward
The PA should support the adoption of non-zero sediment K_ds for Tc particularly for sandy sediments in light of the variability apparent in supporting studies cited in Kaplan (2006a), or demonstrate that lowering the adopted values to zero will have limited effect on modeled performance.

Clarifying Comment FF-17
The text of Figure 4.4-41 in the PA is illegible due to poor image resolution. Provide a higher resolution image.

Performance Assessment Overview

The following comments address general issues associated with development of the FTF performance assessment including recommendations for use of a systematic approach that considers relevant features, events, and processes (FEPs) operable for the disposal facility. Specific comments related to the consideration of various FEPs are discussed (e.g., colloidal transport which could enhance the mobility of otherwise immobile constituents; consideration of seismic affects that could compromise the stability of the disposal facility; and chemical agents in the grout that could enhance radionuclide mobility). Other comment requests clarification regarding how deterministic modeling results beyond 10,000 years and probabilistic modeling results, in general, will be considered in evaluating disposal facility performance; and requests that DOE demonstrate its current understanding of barrier and overall system performance.

To develop the following comments, staff reviewed the PA and supporting documents provided to NRC by letter dated August 20, 2008 (Spears, 2008). The staff's review criteria pertaining to the approach to the performance assessment are contained in sections 4.1, 4.2, 4.4, and 4.6 of NUREG-1854, "NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations" (NRC, 2007).

Comment PA-1
The PA should include a comprehensive, traceable, and clear systematic framework for the consideration of features, events, and processes that could affect the future performance of the waste disposal system, in order to support a defensible performance assessment.

Basis
A defensible performance assessment should contain a technical rationale for those features, events, and processes that have been included in the performance assessment, as well as those that have been considered but were excluded. The features, events, and processes should be considered in light of available data and current scientific understanding and typically include attributes of the disposal system setting, degradation of the engineered barriers, and interactions between engineered and natural barriers as well as disruptive events. The identification of features, events, and processes in a systematic framework should be comprehensive, but not driven by open-ended speculation, and the documentation of their technical justification for inclusion or exclusion should be clear and traceable. A defensible transparent and traceable analysis of features, events, and processes would provide a clear understanding and confidence in the performance assessment and its results for current and future stakeholders, both internal and external to DOE.

Path Forward
The PA should document a framework that provides: (1) a comprehensive identification of; and (2) a clear and traceable technical rationale for features, events, and processes that have been

included in as well as those that have been excluded from the performance assessment. The documentation of this analysis should also provide a traceable and transparent description of the implementation of included features, events, and processes in the performance assessment model abstractions.

Comment PA-2
The PA should justify excluding consideration of seismic effects on the waste disposal system.

Basis
Section 3.1.4.3 of the PA summarizes the current understanding of the seismic history in the vicinity of the site. The PA states that F-Area potentially could be subject to seismic activity of the Tinker Creek fault, which is associated with activity of the Coastal Plain sediments (page 74). The anticipated impact to F-Area from slip on Tinker Creek fault or other local or regional faults, however, is not discussed in the PA. While it is clearly stated in the PA that slip on the Tinker Creek fault could impact the F-Area, it is not clear whether slip on the local, highly studied, Pen Branch fault could also impact the F-Area.

WSRC (2007) discusses the seismic hazard assessment for the Savannah River Site. WSRC (2007) states that the current DOE criteria are based on probability. While probabilistic seismic hazard assessment is used to estimate the likelihood of exceeding a particular ground motion at a specific location during a time period of interest, the performance assessment lacks a clear discussion of the consideration of seismic events over the time frames of the assessment and the document could more clearly describe the consideration of seismic effects on the stability of the disposal facility including the engineered surface barriers and stabilized tanks, as well as the natural system.

Path Forward
The PA should provide information regarding the expected impact to the F-Area Tank Farm from slip on local and regional faults along with supporting data. If available, provide specific information regarding which SRS faults have seen slip during recent time and details on the extent and observed effects of such slip. If available, provide information regarding the depth of hypocenters and the geologic formation name in which slip has been documented in recent time. Provide technical bases for precluding functional damage to important closure cap layers from seismic shaking (e.g., explain whether geosynthetic layers will be weakened or torn by seismic vibrations). Provide technical bases for the assumption that material settlement (whether through liquefaction or static loading) will be uniform.

Provide a technical rationale for the applicability of the seismic hazard analysis in light of the long time frames considered in the performance assessment for the FTF waste disposal system. If excluded from consideration in the conceptual model, provide a technical rational for exclusion. If included in the conceptual model, provide a clear and transparent discussion of the abstraction of seismic effects on the waste disposal system performance.

Comment PA-3
The PA should contain a traceable and clear description of the implementation of colloid-facilitated radionuclide transport from the waste disposal system, in order to support a defensible performance assessment.

Basis
Section 4.2.3 summarizes the implementation of radionuclide transport processes into the performance assessment. Kaplan (2006a) describes a simplified model for colloid-facilitated

radionuclide transport at SRS in section 3.4.2. However, it is not clear from the current documentation if or how this model is implemented in the FTF performance assessment.

Path Forward
The PA should include a technical rationale for disposition of colloid-facilitated transport. If included, provide a clear description of the implementation of the effects of colloid-facilitated transport in the performance assessment.

Comment PA-4
The PA should include a discussion of the effects of corrosion and degradation products on colloid-facilitated radionuclide migration, in order to support a defensible performance assessment.

Basis
Corrosion products, such as iron hydroxides from corrosion of carbon steel tank liners, and cementitious degradation products, such as colloidal-sized calcium carbonate particles may facilitate enhanced migration of radionuclides that strongly sorb (e.g., plutonium) to subsurface media. Section 3.4.2 of Kaplan (2006a) describes colloid-facilitated transport of contaminants but does not appear to include consideration of steel corrosion products or cementitious degradation products.

Path Forward
The PA should provide a technical rationale for disposition of colloidal-facilitated radionuclide transport due to steel corrosion and cementitious degradation products. This rationale should provide a clear, traceable description of the implementation of the effects of these corrosion and degradation product on colloid-facilitated transport.

Comment PA-5
The results of the performance assessment suggest that the peak dose may occur out to approximately 40,000 years. Representation of the timing and magnitude of the peak dose from the expected evolution of the waste disposal system will be important to adequately understanding the uncertainty in the results of the performance assessment.

Basis
Section 4.4.2 of the PA states that only Configuration A was evaluated for the base case analysis. While analyses considering the effects of the alternate configurations were performed and described in the PA to understand the effects of uncertainty, it is not clear to what extent the information obtained from these alternative evaluations will be used in inform decisions related to the compliance case. A simulation period of 10,000 years is usually expected to be sufficiently long to capture the peak dose from the more mobile long-lived radionuclides (NRC, 2007). However, assessments beyond 10,000 years should be carried out to capture peak dose to ensure that the disposal of certain types of waste (e.g., waste with large inventories of uranium and large inventories of long-lived, less mobile transuranic radionuclides) does not result in markedly high doses to future generations.

Path Forward
The PA should contain an evaluation of the peak dose from the reasonably expected evolution of the waste disposal system. If a deterministic analysis is used to estimate the expected peak dose, demonstrate that the expected evolution is technically defensible and consistent with current scientific understanding. If a probabilistic analysis is used to estimate the peak dose, demonstrate that the potential evolutions are technically defensible and consistent with current

scientific understanding and that the peak mean dose adequately represents the uncertainty and variability in the evolution of the waste disposal system.

Comment PA-6

The PA should contain a more comprehensive and traceable barrier analysis that would provide an improved understanding of the importance of features and processes that limit the flow of water into the waste disposal system, the release of radionuclides from the waste disposal system, or the transport of radionuclides through the environment to the biosphere.

Basis

Section 7.1.1 of the PA describes the integrated disposal system behavior. This section qualitatively describes the capabilities of the various features of the disposal system, both engineered and natural features. A comprehensive barrier analysis typically includes an identification of barriers as well as a description of their respective capabilities to limit the flow of water into the disposal system, the release of radionuclides from the waste disposal system, or the transport of radionuclides to the biosphere. The description of barrier capabilities should provide both a qualitative and quantitative understanding of the barriers' contributions to waste isolation including the effects of uncertainty in the barriers' performance. The description of barrier capabilities should include time periods over which the barriers are effective and the magnitude of the barriers' impact on waste isolation over those time periods for key radionuclides. The description of capabilities should be supported by results of the performance assessment including sensitivity and uncertainty analyses, importance analyses, and intermediate results.

Path Forward

The PA should provide a more comprehensive barrier analysis that clearly identifies barriers to waste migration and describes the capabilities of each barrier as understood from the results of the performance assessment.

Comment PA-7

The PA should provide justification for the inclusion or exclusion of the effects of admixtures on grout degradation and radionuclide release and transport, in order to support a more defensible performance assessment.

Basis

Section 3.2.3 of the PA describes the tank grouting plan for filling and stabilizing the waste tanks. The reducing grout is reported to contain a viscosity modifier (e.g., Kelco-Crete or similar) and a water reducer (e.g., ADVAFLOW or similar). The performance assessment lacks a clear examination of the effects of these admixtures on grout degradation or radionuclide release and transport.

Path Forward

The PA should provide a clear rationale for inclusion or exclusion of the effects of grout admixtures on the waste disposal system in the performance assessment.

Comment PA-8

The results of the PA should clearly support the statement that the peak dose is captured in the reported performance assessment results.

Basis
Sections 5.5 and 5.5.1.5 of the PA both report that the peak dose from FTF releases at 100 m is expected to occur prior to 40,000 years. However, groundwater concentrations plotted in Appendix D, suggest that while Pu-239 concentrations have peaked in sectors D and E for the Upper Three Runs – Upper Zone (UTR-UZ) and Upper Three Runs – Lower Zone (UTR-LZ) aquifers, Pu-239 concentrations are still increasing in sectors A, B, and C in the 50,000 year simulations, and it is not clear, for instance, that the peak dose for Sector E bounds the results for Sector A.

Path Forward
The PA should provide a demonstration that the results of the performance assessment capture the peak dose due to releases from the FTF.

Clarifying Comments—Performance Assessment Overview

Clarifying Comment PA-9

The PA should explain the discrepancy in peak radionuclide flux from the containment and into the upper aquifer.

Basis
Tables 5.1-1 and 5.1-2 report peak fluxes of key radionuclides from containment and into the upper aquifer, respectively. For instance, the source of the peak flux from containment for technetium-99 and plutonium-239 is from 242-3F Concentrate Transfer System (see Table 5.1-1) while the source of peak flux entering the upper aquifer is reportedly from transfer lines and Tanks 17-20, for the respective radionuclides (see Table 5.1-2). Also, the flux of protactinium into the upper aquifer (see Table 5.1-2) suggests a long delay but no reduction compared to the flux leaving containment (see Table 5.1-1) while neptunium and lead reportedly have shorter delays but larger flux reductions.

Path Forward
The PA should provide an explanation for the apparent discrepancies between fluxes for key radionuclides from containment (Table 5.1-1) and entering the upper aquifer (Table 5.1-2).

Clarifying Comment PA-10

Section 5.5.1 of the PA discusses the groundwater pathway dose results including the dose spike attributed to Ra-226 within the first 20,000 years. The discussion attributes the source of the radium to decay of U-238. Given the relative similarities in initial inventories of U-238 and U-234 and the longer half-life of U-238, it seems likely the source of the radium is the decay of U-234 rather than U-238.

Uncertainty/Sensitivity Analysis

The purpose of DOE's probabilistic analysis is to estimate the range of potential doses that results from variability and uncertainty in parameters considered in the PA. The probabilistic analysis was conducted using GoldSim software through simulation of different conceptual models and by propagating uncertainty in parameter values. The results of the probabilistic modeling were used to identify the most risk-significant parameters and assumptions to be targeted for more detailed study. Because DOE based its compliance on a deterministic model, assuming a base case Configuration A,[2] and since Configuration A is only one of many possible conceptual models, it was important for DOE to quantify the sensitivity of the results to other conceptual models or parameter values.

The following comments address DOE's uncertainty and sensitivity analysis. The majority of the comments address the potential for certain assumptions and approaches taken to significantly reduce the peak of the mean dose. The peak of the mean dose is the maximum dose of the time history curve resulting from the mean of all the realizations within DOE's probabilistic analysis. Specific data or additional discussion regarding parameter distributions (e.g., K_ds and solubility limits) are recommended as they have a significant impact on the magnitude and timing of the peak dose. The comments also address the integration of separately developed submodels (including the adjustments and translation required in switching from the PORFLOW deterministic to the GoldSim probabilistic model). In many cases separate conceptual models are used to define parameter distributions (e.g., steel liner failures; and physical degradation, flow rates, and chemical transitions of cementitious materials) within the tank environment. Comments include suggestions for increasing the transparency of the integration of submodels in order to more accurately quantify the uncertainty associated with performance assessment model predictions.

To develop the following comments, staff reviewed the PA and supporting documents provided to NRC by letter dated August 20, 2008 (Spears, 2008). The staff's review criteria pertaining to the approach to sensitivity and uncertainty analysis are contained in sections 4.2, 4.4, 4.5 and 4.6 of NUREG-1854, "NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations" (NRC, 2007).

Comment UA-1

The PA should specifically address the potential for "risk dilution" based on the manner in which parameter and conceptual model uncertainty is considered in the stochastic analysis.

Basis

Risk dilution is a term related to probabilistic modeling that is used here to describe the spreading out in space or time of contaminant releases and resulting dose due to the manner in which the stochastic analysis is implemented. Risk dilution can be significant from the standpoint that it could lead to an unjustifiable reduction in the peak of the mean dose which is a typical endpoint used to demonstrate compliance with performance criteria. Due to the complexity of the SRS FTF model, there is a potential to unintentionally reduce the magnitude of the peak dose. Risk dilution could be a result of the number of simplifying assumptions that need to be made to make the problem more manageable or due to the large uncertainty associated with many of the parameters or processes being simulated. DOE's treatment of aleatory and epistemic uncertainties in the model may have a large impact on the calculated peak of the mean dose (e.g., assumptions regarding variability of failure times of steel liners for different tanks [aleatory] or uncertainty in the thickness of steel structures [epistemic]).

---

[2] Configuration A assumes that no release occurs until the steel liner fails at some point in the future with no fast pathways assumed through the tank system. Configuration B is similar to Configuration A except that the physical degradation of the cementitious material occurs more rapidly (assumed to fail at 500 yeas). Other possible conceptual models include fast pathways through the tank (Configuration C), or through both the tank and the basemat (Configuration D). Configuration E provides a scenario where the water table rises above the bottom of the tanks, and Configuration F considers a soil cover in lieu of an engineered surface barrier.

For example, steel liner failure distributions for more risk-significant tanks and waste release configurations cover a large range of failure times that span a few tens of years to tens of thousands of years. The time to failure and initiation of waste release is sampled independently for each tank, leading to the potential for waste releases to be spread out over time. While assuming the tanks fail at different times is certainly valid, the parameter distributions for steel liner failure may not be fully supported as discussed in several near-field comments. The time to failure represents several lumped parameters that are varied in a single conceptual model employed for steel liner failure (e.g., steel liner in contact with cement). In order to account for alternative conceptual models and more complex processes, a broad range of parameter values is sampled (e.g., diffusion coefficients) to bound the failure times. In reality, the shape of the liner failure time distribution would likely be different depending on the conceptual model (e.g., steel liner in contact with cement or soil). The impact of the selected parameter distributions for steel liner failure on peak dose over long simulation timeframes is not clear. Other parameter distributions are also expected to affect the magnitude of the peak dose (e.g., lower probabilities for more risk-significant waste release configurations will tend to reduce the peak of the mean dose due to the averaging process of these configurations with less risk-significant configurations). Thus, DOE should identify those parameter distributions that have the largest impact on peak dose and provide support for these distributions commensurate with their risk-significance.

The potential for risk dilution can be partially evaluated by comparing results of the peak of the mean dose, which is more prone to risk dilution, versus the mean of the peak dose. DOE results show that the peak of the mean dose at any well over a 50,000 year simulation timeframe is very broad. The peak of the mean dose is about 100 mrem/yr, and occurs over tens of thousands of years starting around year 20,000. The reason for the broad peak may be strongly tied to the assumption regarding waste tank failures. The mean of the peaks for the 10,000 year compliance period is around 10 mrem/yr; however, no information is provided regarding the mean of the peak dose from 10,000 years to 50,000 years (see Table 5.6-11; WSRC, 2008). A comparison of the peak of the mean to the mean of the peak dose would also provide useful information to assist with evaluating the potential extent of risk dilution due to the timing of the peak dose from realization to realization.

Path Forward

The PA should identify those parameters and processes that have a significant impact on the timing of the peak dose and evaluate the potential for risk dilution due the manner in which contaminant releases are spread out over time in the probabilistic analysis. Parameter distributions should be supported with the level of support commensurate with their risk significance.

The PA should also present additional information regarding the mean of the peak dose that is not constrained to a 10,000 year simulation period (i.e., expand dose results in Table 5.6-11 to 50,000 years). NRC staff recommends that DOE include statistics on the time of the peak dose (e.g., cumulative distribution function for time of peak dose). Compare the statistics for the peak of the mean and mean of the peak dose over the 50,000 year simulation timeframe as a means of partially evaluating potential risk dilution. Provide additional discussion to explain the very broad peak of approximately 100 mrem/yr (see Figure 5.6-21) from around 20,000 to 40,000 years and explain if this extended peak is due to the manner in which the tank failures were sampled and spread out over time. DOE should also evaluate other factors that may lead to potential risk dilution within individual realizations. In general, DOE should demonstrate its understanding of the important factors affecting the magnitude and timing of the peak dose for individual realizations, as well as the peak of the mean dose curve over longer simulation timeframes.

Comment UA-2

The PA should provide additional clarification and discussion on the sufficiency of the approach used to consider uncertainty in important parameters such as solubility limits and K_ds for key radionuclides.

Basis

Selection of solubility limits for key radionuclides is expected to be highly uncertain and one the most important parameters affecting peak dose. One would expect that the peak dose for a radionuclide that is solubility limited can be significantly lowered and delayed compared to a radionuclide with no assumed solubility control. However, results of the sensitivity analysis indicate minimal impact of solubility limits on the peak dose (only one partial dependence plot shows a potential sensitivity of Pu-239 concentration to solubility limit in Figure 5.6-35). This suggests low sensitivity of the peak dose to the solubility limit. This result may be related to the manner in which solubility is treated in the performance assessment. Although uncertainty with respect to selection of the solubility limiting phase was considered in the analysis, it is not clear that uncertainty in the actual solubility limit for a particular phase was considered. Denham (2007) suggests that thermodynamic data uncertainties alone could propagate to as much as two orders of magnitude uncertainty on solubility limits. Furthermore, it is not clear whether uncertainty associated with the solubility limiting phase for oxidizing Region III, which is expected to be the most risk-significant solubility condition, was considered. Given the significance of solubility control on the results of the analysis, additional evaluation and discussion regarding the importance of solubility control and the adequacy of the approach used to implement solubility control appears warranted.

The selection of the distribution coefficients for the basemat and natural system materials also has a significant impact on the results of the performance assessment. In fact, most of the partial dependence plots in Chapter 5 based on the stochastic modeling show a strong influence of radionuclide K_d on the peak dose for members of the public. Table 5.6-19 presenting results from PORFLOW sensitivity analysis also shows a strong dependence of the peak dose on K_d of the basemat and soils with peak dose varying several orders of magnitude even when variability in the K_d is constrained to minimum and maximum values less than a factor of five surrounding the basecase value. Because uncertainty associated with radionuclide K_d is expected to be radionuclide-specific with greater uncertainty associated with radionuclides for which site-specific data is not available, the basis for the assumed range of K_ds for the stochastic analysis (i.e., based on the magnitude of K_d [factor of 3.3 for K_ds greater than 1000 L/kg] should be clearly provided while recognizing that overly broad distributions may lead to risk dilution).

Path Forward

The PA should justify treatment of uncertainty with respect to solubility limits and clarify whether uncertainty in the solubility limiting phase for oxidizing Region III was considered. Provide justification for bounding the value of K_d for key radionuclides based on the magnitude rather than the expected uncertainty associated with the radionuclide-specific K_ds.

Comment UA-3

The results of the deterministic analysis should be compared to the stochastic analysis over a time period that is expected to capture the peak dose.

Basis

A deterministic analysis is used in the PA to demonstrate compliance with performance objectives for FTF closure. A supplementary stochastic analysis is also conducted. The stated objectives of the supplementary analysis are to: (1) evaluate uncertainty in modeling predictions and (2) judge the reasonableness of basecase modeling results. However, limited information and discussion is provided comparing deterministic and probabilistic modeling results. For example, Figure 5.5-9 shows that the peak dose in the deterministic analysis occurs at around year 28,000; however, no information comparing the peak of the mean dose (or mean of the peak dose) with the deterministic peak dose is provided.

The deterministic peak dose is similar to the 75th percentile and mean dose from the stochastic analysis (see Figure 5.6-20 of the PA) within the 10,000 year simulation, while the peak dose within 20,000 years in the deterministic analysis is very low at around 6 mrem/yr compared to the results of the probabilistic analysis presented in Figure 5.6-21 of around 100 mrem/yr. These results suggest that the deterministic analysis tends to under-predict the potential doses associated with releases from the FTF around the 20,000 year time period.

Upon further inspection, however, it appears that the peak dose of around 335 mrem/yr at 28,000 years from the deterministic analysis is significantly higher than the peak of the mean dose at around 100 mrem/yr suggesting that the peak dose from the deterministic analysis occurs later than the probabilistic analysis results show and tends to over predict the potential dose if longer simulation times are considered.

Path Forward

The PA should include additional information comparing the probabilistic analysis results to the deterministic results including the factors influencing the peak dose (e.g., tanks, radionuclides, and parameters). This information should include a discussion regarding both the peak of the mean and mean of the peak dose with respect to how they compare to the deterministic analysis results. If the probabilistic analysis is not considered robust enough to make these comparisons, clarifying information on the objectives of the probabilistic analysis is warranted.

Comment UA-4

Barrier contributions should be adequately evaluated in the PA to identify attributes of the disposal site that are important to performance. Results of sensitivity analyses evaluating barrier contributions in the performance assessment should be more comprehensive and transparent.

Basis

Engineered (e.g., cap, steel liner, and cementitious waste form) and natural systems (e.g., clay lens in vadose and saturated zone; and groundwater dispersion/dilution) are expected to have a large impact on the results of the performance assessment. In many cases, DOE attempts to evaluate the impact of engineered system performance through evaluation of different “Configurations” representing failures or changes in conceptual models for engineered barriers that affect waste release. However, a comprehensive evaluation and documentation of the importance of these barriers in attenuating releases into the environment and limiting exposures to members of the public is not provided in the performance assessment (WSRC, 2008).

For example, Configuration F evaluates the impact of the engineered surface barrier on performance; however, no specific details or results regarding Configuration F are provided in the performance assessment. Configuration E provides a scenario where the water table rises above the bottom of the tanks; however, results from this analysis were similarly not provided.

Configuration D provides a scenario where fast flow pathways exist through the entire system. Figures 5.6-43 and 5.6-44 present results from deterministic runs using basecase parameters with Configuration D assumptions for flow and failure times with only ten percent of the inventory in contact with the fast flow pathway. The basis for assuming only ten percent of the inventory is in contact with the fast pathway is not clear. It is also not clear if this assumption is assumed for all realizations where Configuration D is selected in the stochastic analysis. Nonetheless, the results do not appear to reflect the impact that pessimistic assumptions regarding cementitious and steel liner barrier performance would be expected to have on performance. A statement is made that since the release rates of other radionuclides most affecting dose are solubility limited (e.g., Tc, U, Pu), then their contribution to peak doses are not greatly affected by the change to Configuration D (page 637 of the PA). However, with the exception of Type IV tanks presented in Table 4.4-5, according to the timelines presented in Tables 4.4-2 through 4.4-4, contaminated zone transitions occur virtually instantaneously upon steel liner failure (e.g., signaling a drastic change in solubility for these radionuclides) so it is not clear why these rapid transitions do not impact the results within the 20,000 year timeframe reported. If the impact of increased solubility is not realized until after 20,000 years, then the timeframe of the simulation should be extended to provide useful information regarding the sensitivity of the results to fast flow pathways. Additionally, it is not clear why rapid transition times to oxidized Region III need to be simulated separately (see page 640 and Figures 5.6-45 and 5.6-46 of the PA), if the transitions occur almost instantaneously upon steel liner failure as indicated in timelines in Tables 4.4-2 through 4.4-4 of the PA. This additional simulation may have been necessary for Type IV tanks which do not experience instantaneous chemical transition upon steel liner failure similar to other tanks (Table 4.4-5 of the PA). However, the inclusion of this additional simulation increases ambiguity in the actual chemical conditions assumed in the waste pore fluid for Configuration D.. Furthermore, it is not clear why the chemical transition for Type IV tanks is not instantaneous upon steel liner failure in Configuration D as it is for other tank types.

Other results of the sensitivity analysis are also not fully explained. For example, Figure 5.6-23 shows that the tank Configuration parameter has a significant affect on the 10,000 year dose. No discussion regarding the impact of tank Configuration on dose is provided (e.g., results for Configuration A and B are nearly identical and doses from C, D, and E/F are higher than Configuration A/B, but no explanation is provided).

Statements are made that early steel liner failure leads to reduced doses when Ra-226 doses dominate the peak dose (within 20,000 year simulation timeframes). However, results on page 617 of the PA indicate that earlier failure times can lead to significantly higher doses for what appears to be the intruder groundwater pathway (WSRC, 2008). No discussion regarding these results is presented (e.g., higher doses associated with early releases of short-lived radionuclides into groundwater).

While natural system parameters were evaluated in the sensitivity analysis, the analyses and documentation could be more comprehensive. For example, no information is provided in Section 7.1, which briefly discusses barrier contributions, on the impact of groundwater dilution and attenuation in clays in the saturated zone, although the sensitivity analysis results show that groundwater dilution is one of the most risk-significant parameter values. Furthermore, transparency could be increased with respect to the effective “dilution factor” in the saturated zone based on infiltration rate, aquifer thickness and Darcy velocity; and the representation of clay lens in the GoldSim model.

Path Forward

The PA should include additional results and discussion regarding tank configurations B-F. The PA should also: Address the issue described above regarding the ambiguity of chemical transition and inventory assumptions associated with Configuration D in the sensitivity analysis; Explain the delay in the chemical transition time for the contaminated zone for Type IV tanks in Configuration D; Address the relative risk significance of Configurations A-F including an explanation of why results for Configurations A and B and E and F, which represent two different conceptual models (e.g., tank Configuration E reflects water table rise and tank Configuration F represents a soil cover) are similar, and; Fully evaluate the impact of steel liner failure on the results, including an explanation of when early steel liner failure may lead to higher doses.

The PA should also provide additional information regarding the contributions of natural system barriers (e.g., saturated zone) to overall system performance.

Comment UA-5

The stochastic analysis could be more comprehensive in evaluating multiple system failures.

Basis

The function of many of the barriers considered in the performance assessment is similar (e.g., engineered closure cap, grout, and steel liner act as hydraulic barriers limiting waste release). Therefore, information regarding the impact of underperformance of a single barrier may only be obtained when multiple barriers with similar functions are assumed to fail simultaneously (e.g., both the steel liner and surface barrier may need to fail in order to see the full impact of early steel liner failure on dose). If model assumptions regarding performance of a particular system are not fully supported and uncertainty in the performance of these systems not considered appropriately, potential doses may be underestimated.

Nonetheless, the probabilistic analysis is still expected to provide useful information regarding the impact of multiple failures on overall system performance. Given that the results of the probabilistic analysis appear to be skewed (i.e., mean and 75th percentile dose curves are similar), it appears that a few realizations are dominating the peak of the mean dose. These lower probability, higher consequence events are likely attributable to a combination of parameters representing the underperformance of multiple barriers. For example, underperformance of the steel liner, grouted tanks, and basemat (e.g., Configuration D) and natural system (e.g., vadose zone K_ds) represented in Monte Carlo realizations in the stochastic analysis are expected to represent those combinations of failures leading to the highest dose consequences. These realizations should be analyzed in more detail to assess the relative risk of longer-lived, less mobile constituents.

Path Forward

The PA should include an evaluation of the impact of increased infiltration for those tank configurations representing early steel liner failure (e.g., Configuration D and E). The PA should also provide more detailed discussion regarding the combination of failures that lead to the highest dose consequences and specifically discuss the likelihood of these scenarios. For example, given the low probabilities assigned to high-risk tank Configurations, it would be helpful to provide additional statistics on the peak of the mean dose (e.g., ninety-ninth percentile dose) over the 50,000 year simulation timeframe and additional information on the attributes of the handful of realizations that are dominating the peak of the mean dose curve. This additional information and discussion will assist with interpretation of the results of the probabilistic analysis.

Comment UA-6
Section 5.6.2.4 *Benchmarking Process* does not provide benchmarking values.

Basis
Section 5.6.2.4 *Benchmarking Process* on page 561 of the performance assessment (WSRC, 2008) states that two parameters were adjusted: (1) saturated zone velocity, and (2) a factor applied to the GoldSim plume function. Section 5.6.2.7 *Benchmarking Results* states that there are four sets of benchmarking parameters, grouped as follows: (1) Tank 1/3, (2) Tank 5, (3) Tank 17/18, and (4) Tank 34. The values for the benchmarking factors are not provided. The benchmarking factors are applied to account for the site-specific data as reflected in the PORFLOW results. Since the GoldSim model is not available for review, these benchmarking factors are necessary to reproduce the GoldSim model results from the PORFLOW output files. The benchmarking factors can have a significant impact on the magnitude of the peak dose and any large changes to the GoldSim model to match the PORFLOW results should be clearly flagged and discussed.

Path Forward
Provide the values of the two benchmarking factors for each of the four groups and explain what benchmarking factors these are a function of. Provide additional information regarding the need for large changes in GoldSim modeling results as reflected in the benchmarking factors.

Comment UA-7
Section 5.6.3 of the PA provides limited basis for the configuration probability by tank type and for the basemat fast flow probability. Additionally, the reason for the delay in the chemical transition time for the basemat for all tank types is not clear.

Basis
Uncertainty is incorporated into the conceptual model by assigning probabilities to each configuration for each Tank type. The combined probabilities for tank configurations C and D (fast flow) are 3.75% for the Tank IV and III and 7.5% for the Tank I types. The low likelihood of these scenarios means that the consequences resulting from them would only be seen in a few of the realizations. These probabilities are primarily based on professional judgment and differences in tank design. For example, the probability assigned to fast flow paths in the tank grout for Type IV tanks is lower based on the fact that Type IV tanks do not have cooling coils. Fast flow through the basemat was higher for Type IV tanks due to the fact that Type IV tanks have thin basemats with drainage channels that lead to a central drain that may not be properly grouted. Type III/IIIA tanks were assigned a lower probability of fast pathway configuration D compared to Type I tanks based on assumption of better materials of construction and improved engineering practices of the basemat compared to the older Type I design.

The development of configuration probabilities by tank type needs to be fully justified. For example, the fact that Type IV tanks do not have a top steel liner does not appear to be considered. Newer Type III/IIIA basemats, as well as Type IV tank basemats, also have a two inch thick leak detection slot with channels designed to drain through a center collection pipe to a sump outside of the concrete enclosure around the waste tanks. Using the same rationale for the Type IV tank drainage channels, one could assume that the Type III/IIIA basemats would also have a higher likelihood of forming a fast pathway through the basemat. The relative probability and significance associated with a fast pathway forming through a shrinkage gap between the steel liner and grouted tank, which may affect all tanks and configurations, versus through a cooling coil was also not specifically evaluated or discussed. In the case of fast pathways along the steel liner from grout shrinkage, other factors (besides tank design) may increase the likelihood of certain waste release scenarios and should be considered.

A basemat fast flow parameter which represents the fraction of flow from the waste tank that by-passes the attenuating properties of the basemat was assigned a triangular distribution based on engineering judgment with 0 percent as the most likely value and 10 percent assigned the upper bound. Given the fact that Type III/IIIA and Type IV tanks have drainage channels in the basemat that may be expected to lead to a higher fraction of by-passing flow, it is not clear if this parameter is related to tank type or configuration probability (which reflects differences in tank designs). It is also not clear why a low probability of by-passing flow is assigned for configuration D, which is a configuration that is inherently based on fast flow through the basemat. Because configuration D is already assigned a low probability compared to basecase configuration A, it is not clear why the impact of the by-passing pathway is further minimized by implementation of a basemat fast flow parameter that limits the by-passing affect.

Tables 4.4-2 through 4.4-5 present timelines for tank system degradation for all tank types. The time to chemical transition for the basemat is significantly delayed for configuration D. Because the time to transition to oxidized Region III in the contaminated zone is assumed to occur almost instantaneously upon steel liner failure for all tank types (except for Type IV as discussed in Comment UA-4) due to the rapid flow through the tank fast pathway, is it not clear why the same effect is not realized for the fast pathway through the basemat in configuration D. As the time to chemical transition can have a significant impact on the peak dose, the delay in the chemical transition for the basemat for configuration D for all tank types should be justified.

Path Forward

The PA should provide additional justification for the probabilities chosen for each tank configuration and for implementation of a basemat fast flow parameter for configuration D addressing the concerns listed above. Clarify the delay in the chemical transition time for the basemat compared to the contaminated zone when fast pathways are assumed to exist through both the tank and the basemat in configuration D. It is recommended that the probabilities for tank configurations be tied to the technical basis for avoiding negative processes in grout performance as well. For example, if shrinkage is not properly mitigated or evaluated, it could lead to a much higher probability of fast pathways being present in all configurations or scenarios. The expected correlation of these parameters values should be evaluated and discussed. As discussed in comment UA4, the impact of the assumed conceptual model for waste release could be more clearly presented. It is recommended that DOE show results for the sub-set of realizations run for individual tank configuration or deterministic runs with each configuration run separately.

Comment UA-8

Section 5.6.3 of the PA does not provide the parameter correlations that are defined in the stochastic model.

Basis

The model contains many stochastic parameters that are expected to influence one another in reality, yet it is not clear if they are modeled as correlated. Correlation of parameters is expected to significantly impact the results of the performance assessment. Examples of parameters related to engineered barrier performance that are expected to be correlated include closure cap degradation and steel liner failure, or steel liner failure and chemical changes in the cementitious material, and failure time for tanks of the same type. Examples of other parameters that are expected to be correlated include saturated thickness for a particular realization; K_ds and bioaccumulation factors; precipitation and irrigation rates, etc. If correlated parameters are not assumed to be correlated or are not correctly correlated, the dose predictions could be significantly underestimated (or overestimated).

Path Forward
The PA should include the correlation coefficients for stochastic parameters that are assumed to be correlated or justify why parameter correlations do not need to be considered.

Comment UA-9
The PA should describe the rationale for providing only the four most sensitive parameters in Section 5.6.6.3.

Basis
Section 5.6.6.3 of the PA, *Summary Statistics for Endpoints,* discusses the important variables for particular endpoints. The top four variables are shown and their sensitivity index (SI) is listed, but justification for only including four parameters is not provided. In some cases a large number of parameter values may affect the endpoint being evaluated and many more parameters ranked fifth or higher may have similar importance with the fourth ranked parameter, but only four parameter values are discussed.

Path Forward
The PA should contain sufficient information regarding important model sensitivities. The PA should provide a rationale for the selection of the top four parameters values from the sensitivity analysis and consider providing information on additional parameters beyond the top four when several parameters may have a significant impact on the endpoint being evaluated (e.g., the PA could include all the variables over a certain sensitivity threshold.)

Clarifying Comments—Uncertainty/Sensitivity Analysis

Clarifying Comment UA-10
The PA should address whether there are other approaches to performing the sensitivity analysis that may lead to more accurate results. The PA states that the sum of the sensitivity analyses should approximate the R^2 value of the linear regression of the GoldSim output versus the Gradient Boosting Model predictions. The sum of the SIs is explained in the PA to be quite low, suggesting poor fits of the Gradient Boosting Model to the GoldSim output. Other models and approaches may produce more meaningful results.

Clarifying Comment UA-11
Results are presented in the PA on page 612 in Figure 5.6-24 that are not intuitive. The Darcy velocity is expected to have an inverse relationship with the dose. Clarify the unexplained results in this figure.

Intruder Comments

DOE performed an intruder analysis to demonstrate compliance with performance objectives related to direct intrusion into the disposal facility after institutional controls are assumed to fail at 100 years. The following comments address issues associated with transparency of intruder calculations which make it difficult to review the information provided.

To develop the following comments, staff reviewed the PA and supporting documents provided to NRC by letter dated August 20, 2008 (Spears, 2008). The staff's review criteria pertaining to the approach to intruder analysis are contained in section 5 of NUREG-1854, “NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations” (NRC, 2007).

Comment IT-1
The description of the intruder dose assessment in the PA should include a description of the individual intruder dose pathways and each pathway’s contribution to total dose. The intruder dose assessment should also include an evaluation of the sensitivity of the total dose to individual dose pathways and parameter values used to calculate total dose.

Basis
Section 6.5.1 of the PA, which is the intruder probabilistic sensitivity analysis, refers the reader to Section 5.6.6, which presents information on the effect of parameter uncertainty on intruder dose. The four most sensitive parameters are presented for the chronic intruder doses within 10,000 and 20,000 years, but sensitivity of parameters to particular pathways is not evaluated, nor is the contribution from each pathway to the endpoints. It is expected that certain parameters may have high sensitivity indexes to particular pathways for the chronic intruder dose. For example, the fraction of time the intruder spends in the garden, which is varied from 0.01 to 0.08 per year, or 100 to 700 hours as indicated by PA Table 5.6-10 is expected to be important to the direct exposure pathway. However, the results are not presented with enough detail to evaluate the reasonableness of each parameter and pathway’s contribution to the dose. In addition, while the chronic intruder dose is evaluated as an endpoint, the sensitivity of the *acute* intruder dose to various parameters is not presented.

Path Forward
The PA should contain additional information pertaining to PA Sections 6.4 and 6.5 for Intruder Analysis Results and Sensitivity/Uncertainty Analysis. This information would include the calculated concentrations of radionuclides in soil from drill cuttings and irrigation such as those presented in the PA for groundwater concentration, individual pathway dose analysis results, and sensitivity/uncertainty analyses described very briefly in PA Section 6.5. In addition, DOE should correct the typographical error in Section 6.5.1 that directs the reader to Figure 5.6-45 and 5.6-46. These figures are unrelated to intruder doses.

Comment IT-2
Section 4.2 of the PA is inconsistent in its description of whether the animal pathway in the chronic intruder scenario includes animal exposure to pasture grass contaminated with drill cuttings.

Basis
Section 4.2.4.2.5 (page 358 of the PA) discusses the exposure pathways for the chronic intruder in the performance assessment. The two pathways evaluated for the chronic intruder include: The ingestion of vegetables grown in garden soil that is irrigated with contaminated well water and contains contaminated drill cuttings; and the ingestion of milk and meat from livestock that eat fodder from a pasture irrigated with contaminated well water. Section 4.2.4.2.5 references Figure 4.2-30, in which pathway bullet number 5 includes livestock that eat fodder from a pasture that is irrigated with well water and which contains drill cuttings.

Based on the equations presented on pages 668 and 669 for the intruder ingestion of beef and milk, and ingestion of vegetables; it would appear that the animal pathway does not include a pasture containing drill cuttings.

Path Forward
Provide clarification and explanation in the PA for the intruder pathways analyzed in the performance assessment, in relation to the actual pathways discussed and the results presented in Section 6.0.

Comment IT-3
Comparison of the peak of the mean dose from the combination of reasonable intruder scenarios to the protection of the intruder performance objective could provide more confidence in any future waste determination using this PA to demonstrate compliance with NDAA Section 3116 criteria.

Basis
Section 6.0 of the PA describes the use of the deterministic PORFLOW FTF model results and the use of the baseline modeling configuration to conduct the inadvertent intruder analysis. While analyses considering the effects of the alternate configurations were performed to understand the effects of sensitivity and uncertainty, it is not clear that these alternate configurations will be used in a future waste determination to demonstrate compliance with NDAA Section 3116 criteria. Section 6.5 describes these analyses in very limited terms, presents no discussion of the probabilistic analysis results, and refers to two figures in Section 5 that do not provide intruder specific sensitivity results.

Path Forward
The PA should provide additional information associated with the conduct of and results from the probabilistic analyses described in Section 6.0. For any future waste determination relying on this performance assessment to demonstrate compliance with NDAA Section 3116 criteria, compare the peak of the mean dose from the reasonable scenarios to the performance objectives.

Comment IT-4
The PA intruder dose assessment contains limited information on the methodology and results of the calculations of radionuclide concentrations in contaminated drill cuttings, and soil mixed with those drill cuttings.

Basis
Section 6.0 of the PA describes the methodology and some of the equations used for the intruder exposure pathway analysis but provides little detail on the specific calculation approach coded into the GoldSim model. In addition, no example results are provided for the radionuclide concentrations in the drill cuttings for the acute intruder exposure pathways, as well as concentrations resulting from the mixing of drill cuttings in garden soil for the chronic intruder pathways. This would include methodology and results of the dilution that would occur in the mixing of drill cuttings with garden soil.

Path Forward
The PA should include additional information on the calculations and results on the calculations used to determine radionuclide concentrations in drill cuttings and soil used to calculate dose to the acute and chronic intruder. This information is necessary to enhance the transparency and traceability of the intruder performance assessment calculations.

References

Atkins, M., D.G. Bennett, A.C. Dawes, F.P. Glasser, A. Kindness, and D. Read. "A thermodynamic model for blended cements." Cement and Concrete Research. Vol. 22. pp. 497-502. 1992a.

Atkins, M., D.G. Bennett, A.C. Dawes, F.P. Glasser, A. Kindness, and D. Read. "Thermodynamic Modeling for Blended Cements." Report DoE/HMIP/PR/92/005. Aberdeen, Scotland: Aberdeen University. 1992b.

Berner, U.R. "Evolution of Pore Water Chemistry During Degradation of Cement in a Radioactive Waste Repository Environment." Waste Management. Vol. 12. pp. 201–219. 1992.

Berner, U.R. “Project Opalinus Clay: Radionuclide Concentration Limits in the Cementitious Near-Field of an ILW Repository.” PSI Bericht 02-26, Nagra NTB 02-22. Villigen, Switzerland: Paul Scherrer Institute. 2002.

Bradbury, M.H., and F.A. Sarott. “Sorption Databases for the Cementitious Near-Field of a L/LLW Repository for Performance Assessment.” PSI Bericht 95-06. Würenlingen and Villigen, Switzerland: Paul Scherrer Institute, 1995.

Budiansky, N.D., L. Organ, J. L. Hudson, and J. R. Scully. "Detection of Interactions among Localized Pitting Sites on Stainless Steel Using Spatial Statistics." Journal of The Electrochemical Society, 152 (4) B152-B160 (2005).

Caldwell, 2005, *Ancillary Equipment Residual Radioactivity Estimate To Support Tank Closure Activities For F-Tank Farm*, CBU-PIT-2005-00120, June 15, 2005.

Caldwell, 1999, *Tank 8F Waste Removal – Pump Tank Concentrations During Dilution Operations*, HLW-STE-99-0023, January 27, 1999.

Cantrell, K.J., K. M. Krupka, W. J. Deutsch, and M. J. Lindberg, 2006. “Residual Waste From Hanford Tanks 241-C-203 and 241-C-204. 2. Contaminant Release Model,” Environmental Science and Technology, 40, 3755-3761 (2006).

Clear, K.C. "Time-To-Corrosion of Reinforcing Steel in Concrete Slabs: Volume 3 Performance After 830 Daily Salt Applications." Federal Highway Administration Report No. FHWA-RD-76-70, Federal Highway Administration, Washington, D.C., 1976.

Denham, M.E. “Conceptual Model of Waste Release from the Contaminated Zone of Closed Radioactive Waste Tanks.” WSRC-STI-2007-00544. Aiken, SC: Savannah River National Laboratory. Washington Savannah River Company. 2007.

Ewart, F.T., J.L. Smith-Briggs, H.P. Thomason, and S.J. Williams. “The Solubility of Actinides in a Cementitious Near-Field Environment.” Waste Management. Vol. 12. pp. 241–252. 1992.

DOE/EIS-0303, 2002., “Savannah River Site High-Level Waste Tank Closure Final Environmental Impact Statement*,”* May 2002. Available at: gc.energy.gov/NEPA/nepa_documents/EIS/eis0303/feis/CHAP_3.PDF.

Glasser, F.P., D. MacPhee, and E.E. Lachowski. "Modelling approach to the prediction of equilibrium phase distribution in slag-cement blends and their solubility properties." M. Apted, and R.E. Westerman, eds. Scientific Basis for Nuclear Waste Management XI. Materials Research Society Symposium Proceedings Vol. 112. Pittsburgh, Pennsylvania: Materials Research Society. pp. 117–127. 1988.

Hay, M. S., K. P. Crapse, S. D. Fink, and J. M. Pareizs, “Characterization and Actual Waste Tests with Tank 5F Samples,” WSRC-STI-2007-00192, Rev. 1, Aiken, SC: Savannah River National Laboratory. Washington Savannah River Company. August 30, 2007

Kaplan, D.I., and J. Coates. “Concrete K_d Values Appropriate for the Tank Closure Performance Assessment.” WSRC-RP-2007-01122. Aiken, SC: Savannah River National Laboratory. Washington Savannah River Company. 2007.

Kaplan, D.I. “Geochemical Data Package for Performance Assessment Calculations Related to the Savannah River Site.” WSRC-TR-2006-00004. Rev. 0. Aiken, SC: Savannah River National Laboratory. Washington Savannah River Company. 2006a.

Kaplan, D.I., “Suggested Sorption Parameters for Uranium onto the Walls of High-Level Waste Tanks,” WSRC-STI-2007-00684. Aiken, SC: Savannah River National Laboratory. Washington Savannah River Company. 2006b

Krupka, K.M. and R.J. Serne. NUREG/CR–6377, PNNL–11408, “Effects on Radionuclide Concentrations by Cement/Groundwater Interactions in Support of Performance Assessment of Low-Level Radioactive Waste Disposal Facilities.” Richland, Washington: Pacific Northwest National Laboratory. 1998.

Krupka, K.M., R.J. Serne, and D.I. Kaplan. “Geochemical Data Package for the 2005 Hanford Integrated Disposal Facility Performance Assessment.” PNNL–13037. Rev. 2. Richland, Washington: Pacific Northwest National Laboratory. 2004.

Lunt, T.T., J. R. Scully, V. Brusamarello, A. S. Mikhailov, and J. L. Hudson. "Spatial Interactions among Localized Corrosion Sites." Journal of The Electrochemical Society, 149 (5) B163-B173 (2002).

Ming-Te Liang, Li-Hsien Lin, and Chih-Hsin Liang. “Service Life Prediction of Existing Reinforced Concrete Bridges Exposed to Chloride Environment.” Journal of Infrastructure Systems, p. 76-85, September 2002. DOI: 10.1061/(ASCE)1076-0342(2002)8:3(76).

Neck, V., M. Altmaier, A. Seibert, J.I. Yun, C.M. Marquardt, and T. Fanghänel. “Solubility and Redox Reactions of Pu(IV) Hydrous Oxide: Evidence for the Formation of PuO2+x(s, hyd).” Radiochimica Acta. Vol. 95. pp. 193–207. 2007.

Phifer, M.A., et. al., “FTF Closure Cap Concept and Infiltration Estimates, » WSRC-STI-2007-184, Revision 2, Savannah River National Laboratory, October 2007.

Pointeau, I., C. Landesman, E. Giffaut, and P. Reiller. “Reproducibility of the Uptake of U(VI) Onto Degraded Cement Pastes and Calcium Silicate Hydrate Phases.” Radiochimica Acta. Vol. 92. pp. 645–650. 2004.

Savannah River National Laboratory (SRNL). “Life Estimation of High Level Waste Tank Steel for F-Tank Farm Closure Performance Assessment, Rev. 2.” WSRC-STI-2007-00061, Rev. 2. Aiken SC: Washington Savannah River Company. 2008.

Savannah River National Laboratory (SRNL). “Life Estimation of Transfer Lines for Tank Farm Closure Performance Assessment.” WSRC-STI-2007-00460. Aiken SC: Washington Savannah River Company. 2007.

Séby, F., M. Potin-Gautier, E. Giffaut, G. Borge, and O.F.X. Donard. “A Critical Review of Thermodynamic Data for Selenium Species at 25°C.” Chemical Geology. Vol. 171. pp. 173–194. 2001.

Shibata, T. “Corrosion Probability and Statistical Evaluation of Corrosion Data” in Uhlig’s Corrosion Handbook; R. W. Revie, editor. New York: John Wiley & Sons, Inc. pp. 367-392 (2000).

Shine, E.P., 2007, *Preliminary Guidance for the Distribution of Cs, SR, and U Geochemical Input Terms to Stochastic Transport Models*, SRNL-SCS-2007-00011, April 26, 2007.

Spears, T. J., 2008, “Performance Assessment for the F-Tank Farm at the Savannah River Site, Revision 0, dated June 27, 2008,” letter to P. Bubar, U.S. Nuclear Regulatory Commission, August 20, 2008.

Swingle, R.F. “Characterization of the Tank 19F Closure Grab and Core Samples and the Tank 18F Dip Sample.” WSRC-TR-2002-00107. Aiken, SC: Westinghouse Savannah River Company. 2002.

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

U.S. Nuclear Regulatory Commission (NRC). “Consolidated Decommissioning Guidance—Final Report.” NUREG-1757. Washington, D.C.: 2006a.

U.S. Nuclear Regulatory Commission (NRC). Letter from S. Flanders, NRC to M. Gilbertson, DOE, “Requests for Additional Information on Draft Section 3116 Determination for Closure of Tank 19 and 18 at the Savannah River Site” Washington, D.C. March 31, 2006b.

U.S. Nuclear Regulatory Commission (NRC). “Design of Erosion Protection for Long-Term Stabilization.” NUREG-1623. Washington, D.C.: NRC. September 2002.

West, W. L., “Tank 16 Demonstration: Water Wash and Chemical Cleaning Results,” Memorandum to O.M. Morris, DPSP: 80-17-23, December 16, 1980.

WSRC, 2008. “Performance Assessment for the F-Tank Farm at the Savannah River Site,” SRS-REG-2007-00002, Revision 0, WSRC Site Regulatory Integration & Planning, Aiken, SC, (2008).

WSRC, 2007, *DSA Support Documentation – Site Characteristics and Program Description*, Savannah River Site, WSRC-IM-2004-00008, Aiken, SC, Rev. 1, June 2007.

Wyatt, D.E., F.H. Syms, and R. Cumbest, 2005, “High-resolution stratigraphic modeling of the vadose zone at the Savannah River Site low-level radioactive waste trenches disposal facility.” *Environmental Geosciences*. Vol. 12, No. 4, December 2005, pp 267-277.