U.S. Nuclear Regulatory Commission Review of U.S. Department of Energy Non-High Level Waste Determination for Idaho National Laboratory Tank Farm Facility

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ABSTRACT

The National Defense Authorization Act for Fiscal Year 2005 (NDAA) authorized the United States Department of Energy (DOE) to determine whether certain radioactive waste related to the reprocessing of spent nuclear fuel is not high-level-waste (HLW). The NDAA applies to DOE facilities in the States of South Carolina and Idaho. DOE must consult with the United States Nuclear Regulatory Commission (NRC) as part of its waste determination. NRC must coordinate with the affected state to monitor DOE's disposal actions to assess compliance with 10 CFR 61, Subpart C, performance objectives. The performance objectives in 10 CFR Part 61, Subpart C, contain requirements for protection of the public, inadvertent intruders, individuals during operations, and stability of the disposal site after closure. In September 2005, DOE submitted to NRC a draft non-HLW determination for waste incidental to reprocessing, including sodium-bearing waste[1] (SBW) stored in the Idaho Nuclear Technology and Engineering Center tank farm facility (INTEC TFF) at the Idaho National Laboratory (INL). DOE plans to grout the underground tanks and concrete vaults that house these tanks to stabilize the waste *in situ*. DOE prepared a waste determination to demonstrate compliance with NDAA criteria, including a supporting performance assessment to demonstrate compliance with the performance objectives. To carry out its consultative role required by the NDAA, NRC uses a risk-informed,

[1] Sodium-bearing waste is a generic term used to describe radioactive wastes comprised of second- and third-cycle extraction fluid and decontamination fluids. This waste contains less activity and generally poses less risk than first-cycle extraction fluid (first-cycle extraction fluid contains most of the fission products).

performance-based approach in its review of DOE waste determinations and performance assessments to focus on the key natural and engineered system features needed to support its compliance demonstration. These features include (i) the chemical and physical performance of cementitious materials that mitigate the release of radioactivity into the environment; and (ii) natural attenuation of any radionuclide releases from the disposal facility. NRC's review of DOE's waste determination and performance assessment also facilitated development of a monitoring plan for the INTEC TFF. NRC will coordinate with the Idaho Department of Environmental Quality to monitor DOE disposal actions to assess DOE compliance with the 10 CFR Part 61, Subpart C performance objectives.

INTRODUCTION

DOE uses performance assessments to demonstrate compliance with performance objectives for low-level waste in 10 CFR Part 61, Subpart C. Performance assessments for radioactive waste disposal typically integrate several process models to simulate initiating events, release of radioactivity from engineered systems, flow and transport of constituents in the natural environment, and exposure of potential receptors to residual contamination over time periods that can span thousands of years. DOE prepares performance assessment models with a level of complexity that is dependent on the site characteristics and the capability of less complex process models to collectively demonstrate compliance with performance objectives. Because DOE non-HLW determination documents and supporting information are often voluminous, NRC uses a risk-informed, performance-based approach to identify and focus on the most risk-significant aspects of DOE's performance demonstration during its review.

In the case of the INTEC TFF, NRC reviewed a performance assessment developed by DOE prior to passage of the NDAA in one of its first high-level waste tank reviews. During this review, NRC staff concluded in a technical evaluation report [1] that DOE should (i) investigate the sensitivity of the model results to distribution coefficients (K_ds) for a range of chemical conditions in the tank grout and concrete vaults; (ii) attempt to reduce uncertainty in the inventory for two contaminated sand pads[2]; (iii) re-evaluate significant underestimates of post-cleaning tank inventories based on sampling; and (iv) provide additional justification for sorption coefficients for concrete, basalt, and sedimentary interbed materials. In reaching its conclusions, NRC staff also assumed that significant degradation modes and mechanisms were evaluated in the cementitious material degradation modeling that was used to estimate failure times and that further hydrological model uncertainty would not significantly alter DOE's performance assessment conclusions. The areas enumerated in the staff's 2003 technical evaluation report were the focus of NRC staff's review of INTEC TFF closure under the NDAA in 2005–2006.

PROCESS

DOE and NRC follow an established consultation process under the NDAA [2] based in part on precedents established for incidental waste (or waste incidental to reprocessing) reviews performed by the NRC prior to the NDAA. This process includes DOE submittal of a draft waste determination to NRC for review. NRC reviews this information and generates a request for additional information to assist with its preparation of a technical evaluation report documenting NRC staff's conclusions with respect to DOE's ability to meet NDAA criteria. DOE publishes a

[2] Two sand pads underlying high-level waste tanks were accidentally contaminated in 1962 as a result of back-siphoning of first-cycle extraction fluid from the tanks to concrete vaults that house the tanks and the sand pads.

final waste determination considering the information provided in NRC’s final technical evaluation report. Public meetings between NRC and DOE occur, as needed, during the review process to discuss technical issues.

In the case of the INL review, NRC reviewed an incidental waste determination in 2002–2003 for the INTEC TFF and issued a technical evaluation report in 2003 [1]. DOE revised its performance assessment [3] to include additional analyses conducted to address technical issues raised by NRC. In its 2005 waste determination [4], DOE addressed recommendations made by NRC in its 2003 technical evaluation report including conducting a literature search to provide support for distribution coefficients used in its analysis. DOE also presented new post-tank-cleaning sampling data and revised its dose estimates. NRC issued requests for additional information related to the quality of the residual sampling; development, validation and verification of the sand pad inventory; and cementitious material degradation and contaminant fate and transport process models and support [5]. DOE provided responses to these requests for additional information and met with NRC in June 2006 to discuss remaining issues prior to NRC’s completion of a technical evaluation report in October 2006 [6]. DOE issued a final waste determination in November 2006 considering the major conclusions in NRC’s technical evaluation report [7].

IDENTIFICATION OF KEY RISK DRIVERS

A major part of NRC staff’s review of DOE waste determinations is evaluation of the technical basis for the final list of key or highly radioactive radionuclides that are the focus of waste retrieval activities[3] at DOE facilities. NRC defines highly radioactive radionuclides as those radionuclides contributing most significantly to the risk to members of the public, workers, and the environment. DOE uses a performance assessment to identify the radionuclides that contribute most significantly to dose to members of the public. Many of the highly radioactive or key radionuclides are common from site to site (e.g., Tc-99 and I-129, because these radionuclides are long-lived and relatively non-sorbing in most geochemical environments). Table I lists expected highly radioactive radionuclides based on DOE performance assessment models at INL and two other facilities at Savannah River Site (SRS), South Carolina, covered by the NDAA.

DOE identified highly radioactive radionuclides based on a screening analysis in the performance assessment prepared for the INTEC TFF [3]. An NRC staff probabilistic analysis showed that several other radionuclides could also be key radionuclides. However, historical releases from the INTEC TFF that have migrated to perched water underneath the facility show that primarily Tc-99, I-129, Sr-90, and C-14 have been detected in perched water samples, suggesting that natural attenuation processes are operable for other constituents identified by NRC. Recently, Cs-137 was also detected in the perched water (suggesting that subsurface materials have a higher attenuation capacity for Cs-137 than the other radionuclides detected in perched water). The concrete vault and grouted waste form are expected to provide a significant barrier, mitigating the release of radiological constituents into the environment, whereas the historical groundwater contamination resulting from a piping release was a direct release of waste into the subsurface at TFF. NRC staff will continue to review monitoring data to identify

[3] In addition to providing that performance objectives must be met, the NDAA also requires that highly radioactive radionuclides are removed to the maximum extent practical.

any new and significant information related to DOE's list of highly radioactive radionuclides for the INTEC TFF.

Table I. Expected Highly Radioactive Radionuclides for the Groundwater Pathway at DOE Facilities Based on DOE Performance Assessment Results

Radionuclide	INL	SRS (Saltstone)	SRS Tanks 18 & 19
Tc-99	X	X	X
Sr-90	X		
I-129	X	X	
C-14	X		
Se-79		X	
Np-237			X

SIMPLE CONCEPTUAL MODELS AND CALCULATIONS

NRC staff used multiple methods to support its conclusions following its review of the INTEC TFF waste determination and performance assessment. This incremental review approach included use of basic models and calculations to provide high-level information on the key processes driving most of the risk-reduction. Again, focusing on the key processes identified during NRC's initial review, NRC staff determined a rough estimate of the magnitude of risk reduction afforded by (i) the reducing capacity of tank grout, (ii) sorption and decay of short-lived radionuclides in the sand pad, and (iii) sorption and decay along the flow path through the unsaturated zone. Maximum concentrations in the waste pore fluid (assuming the entire inventory was present in the waste pore volume) were calculated for key radionuclides that drive risk for the groundwater pathway (i.e., Sr-90, Tc-99, and I-129). Next, the expected magnitude reduction in concentration (and consequently dose) was calculated for engineered and natural systems to account for sorption based on simple calculations such as the fraction of inventory sorbed for reducing and oxidizing conditions in the grouted tank waste (Tc-99 and I-129) or sand pad (for Sr-90); expected decay during DOE performance assessment predicted travel times through the sand pad, and vault floor (for Sr-90); expected sorption and decay during DOE performance assessment predicted travel times through the unsaturated zone (for Sr-90); and expected dilution from Big Lost River[4] seepage to the unsaturated zone and expected dilution at the point the plume enters the Snake River Plain Aquifer. The results of these calculations are summarized in Table II.

[4] The Big Lost River is an ephemeral, losing surface water body in the vicinity of the INTEC TFF that is a significant source of water to the unsaturated zone system over long periods of time, and which has some effect on the persistence of perched water directly underneath the INTEC TFF.

Table II. Rough Estimates of Relative Credit for Various Barriers

	Tc-99	**Sr-90**	**I-129**
Total Barrier Performance Needed for Compliance	4 orders of magnitude	9 orders of magnitude	3 orders of magnitude
Engineered Barrier	1 to 4 orders of magnitude	4 orders of magnitude	1 to 2 orders of magnitude
Natural System	3 to 4 orders of magnitude	8 to 9 orders of magnitude	3 to 4 orders of magnitude
Total Barrier Performance Expected by DOE for the Compliance Case	6 orders of magnitude	12 orders of magnitude	4 to 5 orders of magnitude

The simple calculations agreed well with DOE performance assessment results (i.e., the required risk reduction necessary to meet performance objectives minus the estimated risk reduction of engineered and natural system components compared well with DOE performance assessment predicted safety margin), suggesting that simple models could account for major processes in the overall compliance demonstration roughly within an order of magnitude. It is important to note that the calculations reflect DOE Idaho's conceptual model for radionuclide release and transport in its compliance case and that other processes not accounted for by DOE may also be operable. For example, DOE conservatively assumed that the concrete vault floor would degrade and release radioactivity from the sand pad into the environment beginning after 100 years and that the radioactivity would be released from the grouted tank waste beginning after 500 years (see conceptual model in Figure 1). The hydraulic properties of the degraded waste form and cement vault were assumed to be similar to the surrounding alluvium upon failure. The release of material from the sand pad is modeled separately from tank releases (i.e., the grouted tank waste above the sand pad is not simulated in sand pad release calculations and Figure 1 conceptualizes releases from the grouted tank waste only). Physically, however, it is expected that the cementitious material would degrade gradually over time, losing both structural integrity and depleting reduction capacity, which contrasts with the potentially pessimistic and non-realistic step changes in hydraulic properties and time invariant chemical conditions over the entire period of performance assumed in DOE's performance assessment model. NRC staff investigated the effects of these assumptions in its independent probabilistic analysis.

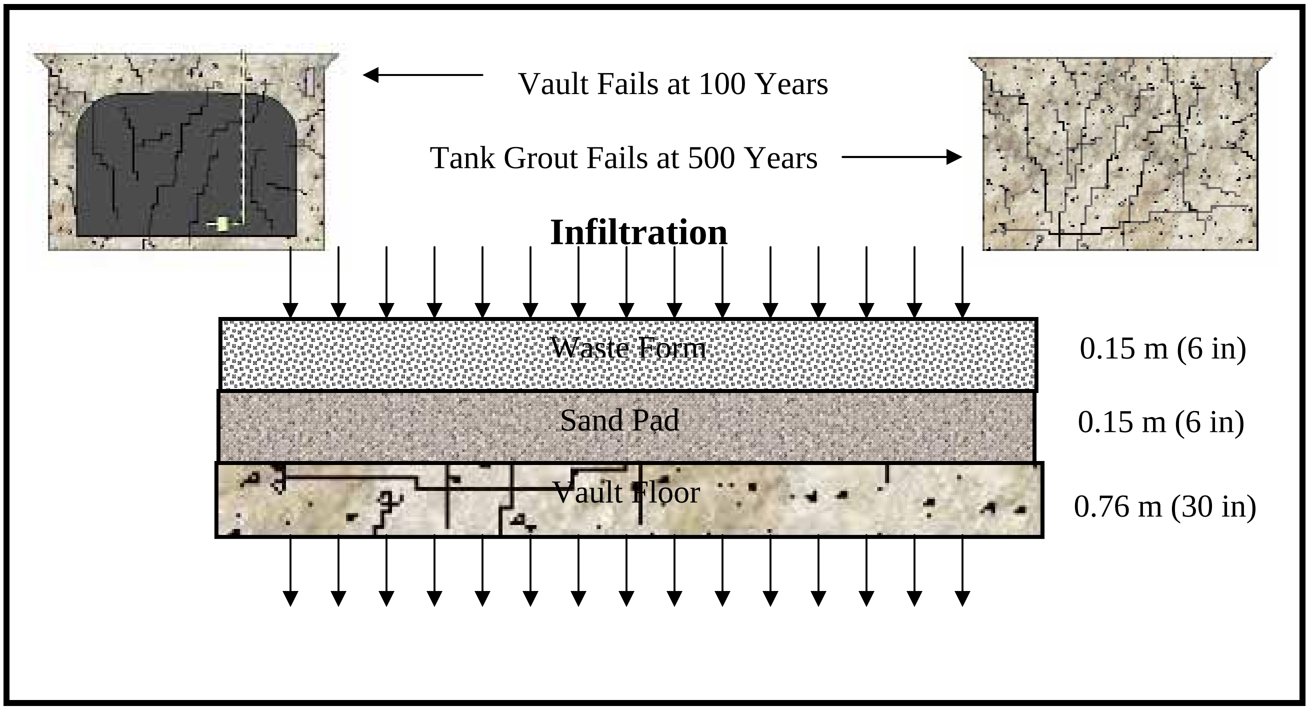

Fig. 1. DOE Conceptual Model of Radionuclide Release

PROBABILISTIC MODELING: REGULATOR’S TOOL TO FOCUS REVIEW

NRC used independent modeling[5] and analysis to focus its review, and identified key attributes of the engineered and natural system performance that were important to meeting performance objectives. Based on the recommendations and insights gained from NRC’s pre-NDAA review, DOE provided additional information in its 2005 waste determination submittal that was used to update NRC’s earlier performance assessment tank model developed by NRC staff during the initial 2002–2003 review. Updates to NRC’s probabilistic model included more recent data collected since the initial review, most notably (i) updated tank inventories (ii) addition of a sand pad source and (iii) updated hydrological parameters. The inclusion of the sand pad source revealed the importance of the short-term performance (first few hundred years) of the concrete vault to mitigate the release of short-lived radionuclides, such as Sr-90 and Cs-137, from the sand pad. On the other hand, risk from short-lived radionuclides is expected to be quite low from the tank waste because the grouted tank waste is expected to remain intact for 500 years, based on DOE’s cementitious material degradation modeling, after which time short-lived constituents will have decayed away. The importance of various barriers was also analyzed through use of switches that alternately turn certain barriers on or off (e.g., reducing conditions; and sorption in the grout, sand pad, and sedimentary interbed). The updated NRC performance assessment model also emphasized the importance of K_ds for constituents such as Tc-99 in grout in predicting release rates to the environment. Other important parameters strongly correlated to

[5] The proprietary software package GoldSim was used to construct the independent, probabilistic model. The GoldSim software package is a visual model building platform for performing dynamic, probabilistic simulations. The software includes a radionuclide transport module that can simulate radioactive decay and in-growth, advection, dispersion, adsorption, diffusion, and matrix diffusion for fracture flow.

dose include infiltration rate, groundwater flow velocity (affecting dilution), and a parameter that accounts for the potential for flow to by-pass sedimentary interbed material through preferential flow paths in fractured basalt (reducing travel times and minimizing attenuation of short-lived, sorbing constituents (e.g., Sr-90) during transport through the vadose zone).

Various conceptual models can be easily analyzed with NRC’s independent modeling. Results from a probabilistic model (Figure 2) reveal that short-lived radionuclides present in the sand pad can dominate the dose at early times because these radionuclides are assumed by DOE to be released when the concrete vault fails beginning as early as 100 years post-closure prior to substantial decay. For short-lived radionuclides, the conceptualization and simulation of preferential flow paths through fractured basalt has a significant effect on the predicted dose, because the attenuation capacity of fractured basalt is expected to be relatively low. At later times during the 10,000 year simulation (Figure 2), Np-237 dominates the predicted dose due to higher sorption coefficients and a longer delay in the peak release of this constituent from the grouted tank and vault system in comparison to other simulated radionuclides.

The effects of step changes in the redox potential for fractions of the waste and the rate of degradation of cementitious materials over time were also investigated probabilistically. Uncertain parameters related to the time of initial failure, the time of step changes in chemical properties, and the degradation rate of the waste form were incorporated into the model to simulate a more slowly degrading waste form. Figure 2 reveals that application of variable degradation rates can lead to multiple peaks for some constituents (e.g., I-129 and Tc-99). The first peak corresponds to the initial source loading when the waste form is only slightly degraded and oxidized, while the second peak corresponds to the peak release from a more degraded waste form. For redox sensitive Tc-99, multiple peaks also occur as a result of changes in the fraction of oxidized waste over time. The actual rate of change of hydraulic and chemical conditions in the cementitious waste forms over time is expected to be variable but highly uncertain. Furthermore, the assumption that the waste and grout are well-mixed may not be valid. Thus, conceptualization and parameterization of degradation and oxidation mechanisms of the grouted waste forms and concrete vaults is a challenge for NRC staff. Because of the risk-significance of engineered barrier performance, the Center for Nuclear Waste Regulatory Analyses (CNWRA) has been tasked by NRC to investigate the risk-significant mechanisms and parameters related to modeling cementitious material degradation for abstraction in radionuclide release models. Information gained from this tasking will be incorporated by NRC staff in future probabilistic analyses. Alternative conceptual models provide valuable information regarding the sensitivity of constituent release rates to time variant conditions in comparison to static models with constant infiltration and chemical conditions.

It is important to note that NRC staff uses the independent modeling only as a tool to provide risk insights, because it is DOE’s responsibility to make its own compliance demonstration and to provide support for its models and model parameters. NRC simply uses probabilistic models as one tool to risk-inform the review and to provide recommendations to DOE with respect to models and model parameters that may require additional support given their uncertainty and risk significance.

Although probabilistic models can be limited in predicting the actual magnitude and timing of peak dose when important parameter distributions are not well known, they serve as valuable tools, supplementing information provided by deterministic models and considering nonlinear effects on peak dose that may not be observed when only one parameter is changed at a time.

Performance assessment modeling is an iterative process and initial analyses should be focused on identifying the most risk-significant processes and parameters. Additional resources can then be spent gathering more information or requesting that DOE provide additional support for process models or parameter values that are important to its compliance demonstration.

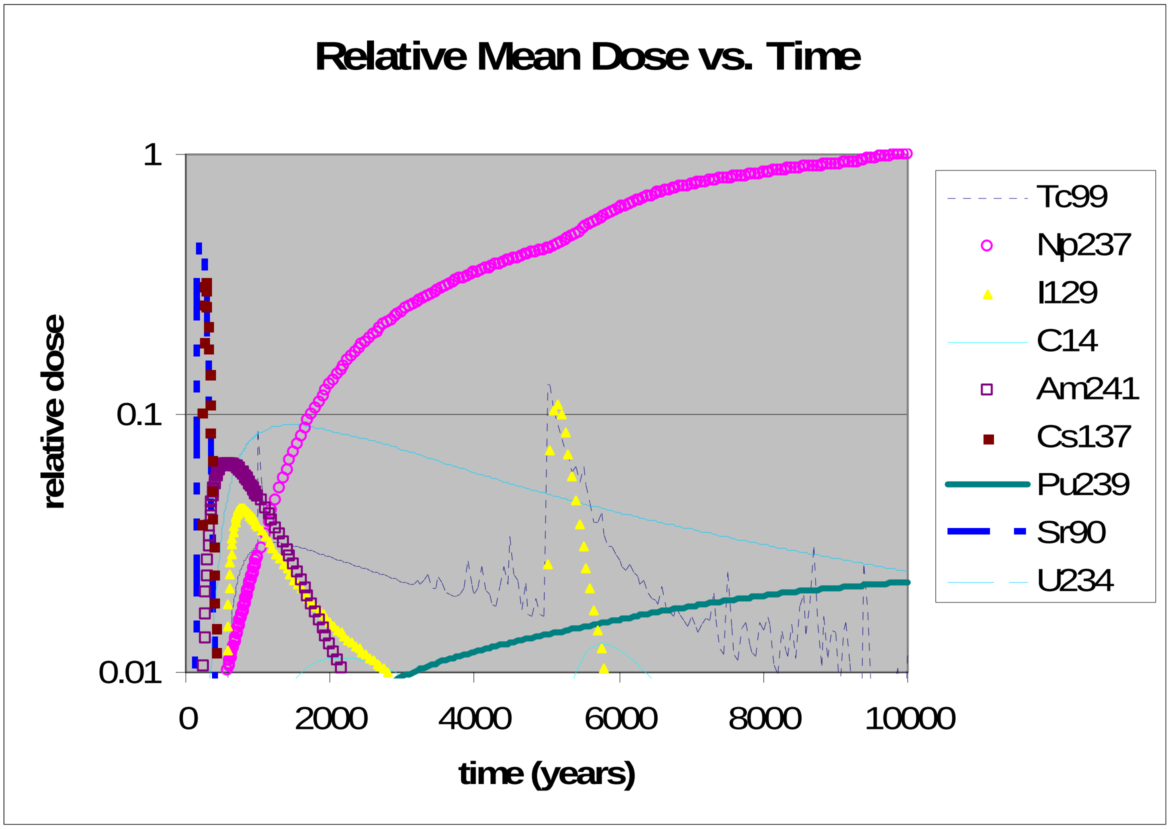

Fig. 2. Example output (mean dose) of NRC's probabilistic model used to test alternative conceptual models for cementitious material degradation and preferential flow

MODEL SUPPORT: MONITORING DATA

NRC staff also takes into account information regarding the natural system in which the disposal facility is located. Valuable information regarding the hydrogeological system at INTEC was obtained through review of data, studies, and modeling reports related to a historical contamination event at the INTEC TFF [8, 9, 10, 11]. This information is useful in assessing whether DOE's conceptual model development and implementation is consistent with current knowledge of the disposal system and of the surrounding environment. In the case of the INTEC TFF, the natural hydrogeologic system is very complex. Supporting information is needed to provide confidence in models and model parameters.

Perched water (see conceptual model in Figure 3) directly beneath the INTEC TFF is contaminated with residual sodium-bearing waste as a result of a 1972 piping leak. Saturated groundwater north of the facility is also contaminated with Tc-99 above maximum contaminant levels established by the United States Environmental Protection Agency, and this contamination has been linked to the INTEC TFF source area [9, 11]. Maximum concentrations of some important contributors to groundwater contamination at the INTEC TFF are provided with Figure 3. Analytical data provides valuable information about the variability in transport rates of various constituents in the natural system, and about the potential flow directions, distances, and transport times through the unsaturated zone. For example, Sr-90 has been detected since the early 1990s in northern perched water in the vicinity of the INTEC TFF with maximum concentrations currently near 200,000 pCi/L [8], while significant attenuation of Sr-90 in the vadose zone has delayed and reduced contamination of the Snake River Plain Aquifer (maximum concentrations of 35 pCi/L). Transport of less mobile Cs-137 to perched water appears to have been significantly retarded with only one well recently showing significant concentrations of Cs-137 at 600 pCi/L. On the other hand, investigators have linked Tc-99 contamination detected in the Snake River Plain Aquifer slightly north of the INTEC TFF (and in a new well located just southeast of the facility) to previous releases from the facility [9, 11] with current maximum concentrations near 3,000 pCi/L [10]. Significantly lower concentrations of Tc-99 are currently present in the vadose zone compared to the Snake River Plain Aquifer. In the case of Tc-99, the low attenuation capacity of sedimentary interbed and basalt subsurface materials appears to have resulted in faster transport times of this constituent through the vadose zone and early impacts to the Snake River Plain Aquifer compared to other key constituents at INTEC TFF.

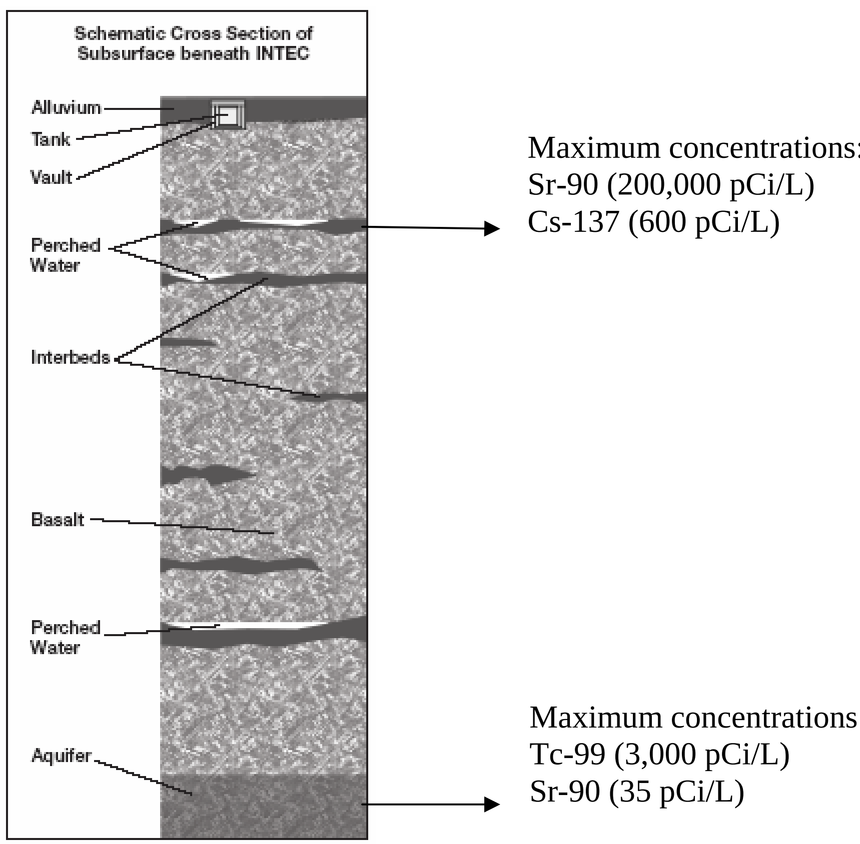

Fig. 3. Schematic of subsurface at the INTEC TFF [12]

Additional data collected to support updated modeling under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) also provides key information regarding infiltration rates, perched water sources, potential flow directions, and transport times. This information was used to evaluate DOE’s hydrogeological conceptual model and modeling results. NRC concluded that DOE’s performance assessment model potentially overestimated the amount of vadose zone attenuation due to dilution by Big Lost River seepage and sorption and decay of short-lived radionuclides along the unsaturated zone flow path away from the TFF. However, with respect to the tank closure performance assessment, Snake River Plain Aquifer dilution and attenuation of short-lived, sorbing constituents in sedimentary interbed material directly beneath the TFF is expected to provide sufficient attenuation capacity to reduce concentrations and dose to acceptable levels, regardless of the limitations and uncertainties in DOE’s far-field hydrology model. Furthermore, monitoring data from previous releases were used to support NRC’s conclusion that future releases of radioactivity from the INTEC TFF are expected to be well below concentrations that could potentially lead to an exceedance of the 10 CFR 61.41 performance objective related to protection of the general population from effluent releases from the disposal facility.

NRC staff is developing a monitoring plan that focuses on the key attributes of the engineered and natural systems identified during review of DOE’s waste determination and performance assessment. The goal of monitoring is to assess compliance with performance objectives in 10 CFR Part 61, Subpart C. NRC staff is coordinating with the Idaho Department of Environmental Quality to begin monitoring activities at the INTEC TFF.

The focus of this paper has been on the 10 CFR 61.41 performance objective related to protection of the general population from releases of radioactivity from the disposal facility; however, 10 CFR Part 61, Subpart C also contains requirements for protection of individuals from inadvertent intrusion (10 CFR 61.42), protection of individuals during operations (10 CFR 61.43), and stability of the disposal facility (10 CFR 61.44). Monitoring will also address compliance with these other performance objectives.

CONCLUSION

NRC's review of the safety of near-surface disposal of radioactive waste at the INTEC TFF was facilitated and focused by risk insights developed with simple models and calculations; probabilistic modeling; and analysis of monitoring data. Review emphasis was placed on those aspects of the disposal system that were expected to drive performance: the physical and chemical performance of the cementitious wasteform and concrete vaults and natural attenuation of any releases from the disposal facility. The risk insights developed from NRC staff’s review of DOE’s waste determination and performance assessment were used to develop a risk-informed, performance-based monitoring plan to assess DOE compliance with 10 CFR Part 61, Subpart C.

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