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Office of Nuclear Materials Safety and Safeguards

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SUBJECT: TECHNICAL REVIEW: PERFORMANCE OF THE HIGH DENSITY POLYETHYLENE LAYER, HIGH DENSITY POLYETHYLENE/ GEOSYNTHETIC CLAY LINER COMPOSITE LAYER, AND THE LOWER LATERAL DRAINAGE LAYER (DOCKET NO. PROJ0734)

The U.S. Nuclear Regulatory Commission (NRC) staff has performed a technical review of the performance of the High Density Polyethylene (HDPE) layer, HDPE/Geosynthetic Clay Liner (GCL) composite layer, and the Lower Lateral Drainage Layer (LLDL) as part of NRC monitoring of U.S. Department of Energy (DOE) disposal actions at the Savannah River Site (SRS) Saltstone Disposal Facility (SDF).

The NRC review was performed in accordance with monitoring activities described in the NRC 2013 SDF Monitoring Plan (Agencywide Documents Access and Management System (ADAMS) Accession No. ML13100A076). This NRC technical review report is related to Monitoring Area 6 (Disposal Structure Performance) and Monitoring Area 10 (Performance Assessment Model Revisions) in that monitoring plan. Within those two monitoring areas, this technical review report addresses Monitoring Factor (MF) 6.03 “Performance of Disposal Structure Roofs and HDPE/GCL Layers”, and MF 10.02 “Defensibility of Conceptual Models”.

In addition to the disposal structure roofs and HDPE/GCL composite layer, MF 6.03 is associated with the long-term performance of the LLDL because it is the contrast between the high hydraulic conductivity of the LLDL and the low hydraulic conductivity of the HDPE/GCL composite layer that allows those components to be an important barrier for maintaining waste isolation. The NRC evaluated information about processes that could reduce the conductivity of the highly permeable LLDL (e.g., clogging of the high-conductivity sand layer) and processes that could increase the assumed low hydraulic conductivity of the disposal structure roofs or HDPE/GCL composite layers overlying the disposal structures. The DOE technical basis for the accumulation and deposition of clay particles on the bottom of the LLDL relies on references from the study of soils. However, it is not clear to the NRC staff if the velocity of the water flowing laterally in the LLDL, with a slope of 1.5% to 2.0%, is sufficiently slow to allow the deposition of clay particles to occur. In addition, the infiltration rate may be important to the rate that the LLDL will fill in with fine-grained sediment because the infiltration rate determines the cumulative water volume flowing into each layer. Thus, if the range of infiltration rates changes, then the DOE may need to reevaluate the filling in or clogging of the LLDL. Also, in the NRC RAI Comment Disposal Structure Performance (DSP)-1 from the review of the DOE SDF Fiscal Year (FY) 2013 Special Analysis Document (SRR-CWDA-2013-00062, Rev. 2), the NRC described the concern related to the observations of water in the leak detection system of SDS 3A. The presence of water in that leak detection system could be due to relatively unusual welds and/or penetrations, but the leak is also consistent with the failure of the HDPE material or an HDPE seam. Those leaks undermine the technical bases for the expected barrier performance of the HDPE layer and the HDPE/GCL composite layer. The NRC understands that those layers have a potentially significant effect on dose and additional information is needed to support the DOE assumptions.

MF 10.02 involves the DOE conceptual model described in the DOE 2009 SDF Performance Assessment (PA) (ADAMS Accession No. ML101590008), as supplemented by the DOE conceptual model in the DOE SDF FY 2014 Special Analysis Document (ADAMS Accession No. ML14316A586). The PORFLOW model from the PA and the PORFLOW model from the FY 2014 Special Analysis Document represent two different conceptual models. The model from the PA represents HDPE/GCL performance that DOE expects and the model from the FY 2014 Special Analysis Document represents performance that DOE assumes with regard to the hydraulic properties of the HDPE geomembrane and the GCL and the amount of water flowing through the wasteform. Although the current evaluation case in the FY 2014 Special Analysis Document assumed sudden and complete failure of the HDPE layer and HDPE/GCL composite layer performance, the NRC staff is concerned that it may not be fully supported or appropriate for all relevant time periods under different circumstances. Frequently, the difficulty of definitively establishing what feature or value is conservative is due to the complexity of the system and the interrelationships and interdependencies of many of the features and processes. The NRC staff recommends that both conceptual models (i.e., the DOE evaluation case and the DOE expected or best estimate case) should be carried forward as sensitivity cases so that insights can be gained.

Enclosure:
Technical Review of Performance of the High Density Polyethylene Layer, High Density Polyethylene/Geosynthetic Clay Liner Composite Layer, and the Lower Lateral Drainage Layer

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Technical Review of Performance of the High Density Polyethylene Layer, High Density Polyethylene/Geosynthetic Clay Liner Composite Layer, and the Lower Lateral Drainage Layer

Date
April 4, 2017

Reviewers
Hans Arlt, Sr. Systems Performance Analyst U.S. Nuclear Regulatory Commission (NRC)
George Alexander, Systems Performance Analyst, NRC

Primary Documents
U.S. Department of Energy (DOE), SRR-CWDA-2009-00017, Rev. 0, "Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site," October 2009. ML101590008

DOE, SRR-CWDA-2014-00006, Rev. 2, "Fiscal Year 2014 Special Analysis for the Saltstone Disposal Facility at the Savannah River Site," September 2014. ML15097A366

DOE, SRR-CWDA-2014-00070, Rev. 0, "Evaluation of Potential Breach of Side Wall High Density Polyethylene (HDPE) Liner on Saltstone Disposal Unit Cell 3A," July 2014. ML14322A315

DOE, SRR-CWDA-2016-00060, Rev. 0, "Action Item Follow-up in Support of NRC Onsite Observation Visit April 19-21, 2016," June 2016. ML16180A311

NRC, "NRC April 19 – 21, 2016, Onsite Observation Visit Report for the Savannah River Site Saltstone Disposal Facility," July 2016. ML16147A197

Background
The High Density Polyethylene (HDPE), HDPE/Geosynthetic Clay Liner (GCL) and Lower Lateral Drainage Layer (LLDL) are described in the NRC 2013 Saltstone Disposal Facility (SDF) Monitoring Plan (ADAMS Accession No. ML13100A076) in Monitoring Factor 6.03 "Performance of Disposal Structure Roofs and HDPE/GCL Layers".

Information from the DOE 2009 Saltstone Disposal Facility (SDF) Performance Assessment (PA) and the NRC 2012 SDF Technical Evaluation Report (TER)

HDPE Layer and HDPE/GCL Composite Layer:
All saltstone disposal structures will eventually be buried and have an engineered surface cover constructed above them to provide the disposal structures with a degree of isolation from the elements and provide stability. Within the cover or closure cap, a 1.5 millimeter (mm) (0.06 inch (in)) thick High Density Polyethylene (HDPE) geomembrane will be used in combination with a 5 mm (0.2 in) thick Geosynthetic Clay Liner (GCL) underneath. An upper lateral drainage layer lies above this HDPE/GCL composite layer. The region between the bottom of the closure cover and the top of the disposal structures includes the following sequence of layers up from the disposal structure roof: a GCL layer, a HDPE layer, a geotextile fabric, a 0.6 meters (m) (2 feet (ft)) thick lower lateral drainage layer (LLDL), and another geotextile filter fabric on top of

LLDL (see Figure 1). The HDPE geomembrane portion of the HDPE/GCL combination layer that will be installed on top of each disposal structure roof has a thickness of 2.5 mm (0.1 in). Both the 150-Foot Diameter Disposal Structures and the 375-Foot Diameter Disposal Structures use an additional HDPE/GCL composite layer in the floor between the upper and lower mud mats, while the 150-Foot Diameter Disposal Structures also apply a single HDPE geomembrane layer on the outside of the cylindrical walls. Unlike the 150-Foot Diameter Disposal Structures and the 375-Foot Diameter Disposal Structures, Saltstone Disposal Structure (SDS) 1 and SDS 4 (previously referred to as Vault 1 and Vault 4, respectively) do not have additional HDPE geomembranes or GCL layers, although SDS 4 does use polystyrene sheet drains to reduce the hydrostatic pressure within the cells.

Figure 1: Layers of the SDF Conceptual Cover
(Right-Side of Figure 3.2-20 in SRR-CWDA-2009-00017, Rev. 0)

The HDPE used for the 150-Foot Diameter Disposal Structures will form an outer lining material while the HDPE/GCL composite layer under the floor will extend 0.6 m (2 ft) up the side of the walls and be welded to HDPE layer that is attached to the cylindrical side walls. The HDPE layer on the sides will be welded to the HDPE/GCL composite layer placed on the roof. As indicated in the DOE 2009 SDF Performance Assessment (PA) (ADAMS Accession No. ML101590008), the original purpose of the HDPE layer covering the walls and the HDPE/GCL composite layer on the roof was to limit the flow of water and oxygen into the disposal structures while the HDPE/GCL composite layer under the floors was designed to limit the flow of water out of the disposal structures. Also the DOE indicated that the HDPE layer was intended to protect the concrete from potentially corrosive soil components and carbonation. This NRC technical review will focus on the HDPE/GCL composite layer on the roof, but will also examine the performance of the HDPE/GCL composite layer under the floor, the HDPE layer used to cover the 150-Foot Diameter Disposal Structures, and the HDPE/GCL composite layer used in the closure cover.

In the PA, the vertical hydraulic conductivity of the vertical HDPE geomembranes lining the 150-Foot Diameter Disposal Structure walls and the horizontal hydraulic conductivity of the horizontal HDPE/GCL composite layers were modeled as remaining unchanged over time with a value of 5.0×10^{-15} centimeters/second (cm/s). The initial horizontal hydraulic conductivity and diffusivity values perpendicular to the vertical HDPE geomembranes were 2×10^{-13} cm/s and 4×10^{-11} cm^2/s, respectively (see Figure 2), while the values perpendicular to the horizontal HDPE/GCL composite layer were modeled by DOE with an initial vertical hydraulic conductivity of 2.8×10^{-12} cm/s and an initial diffusivity of 1.2×10^{-10} cm^2/s (see Figure 3). Those values were modeled as steadily degrading during the first 1,000 years after closure and more slowly until 20,000 years after closure. To derive that projected HDPE layer performance, the DOE considered various HDPE degradation mechanisms and selected those expected by the DOE to cause the most significant degradation. The DOE then estimated the number and size of defects that would form during the performance period based on those degradation mechanisms. Depending on the size of the defects, the defects were classified as pinholes, holes, tears, small cracks, or cracks. Then, the DOE estimated hydraulic properties based on the total estimated area of defects per unit HDPE layer area (see Table 23 in the DOE document, SRNL-STI-2009-00115, Rev. 1).

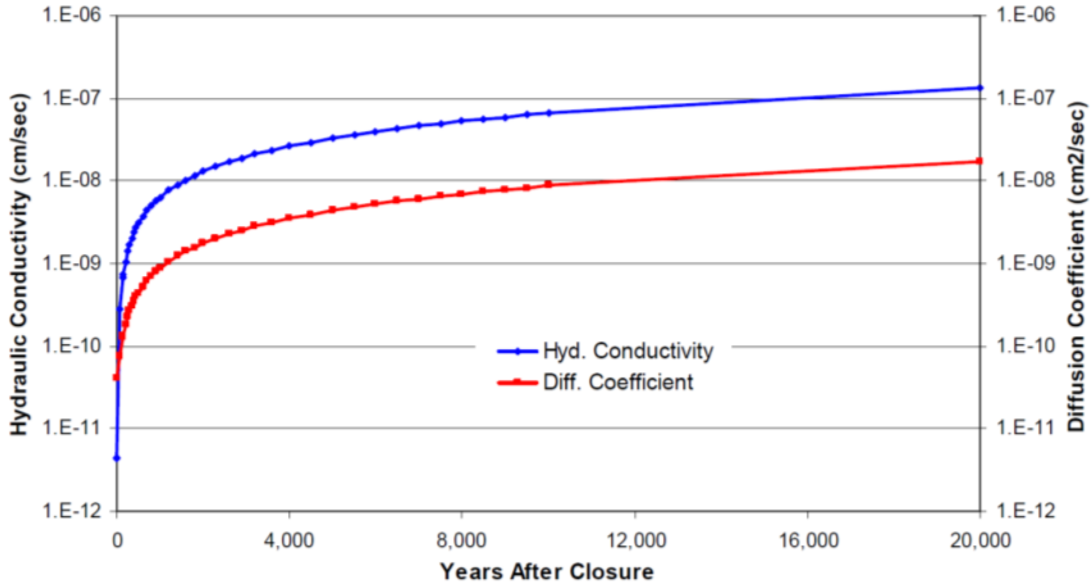

Figure 2: Hydraulic Conductivity and Diffusion Coefficient for the HDPE Layer of the 150-Foot Diameter Disposal Structures after Closure (Figure 4.2-42 in SRR-CWDA-2009-00017, Rev. 0)

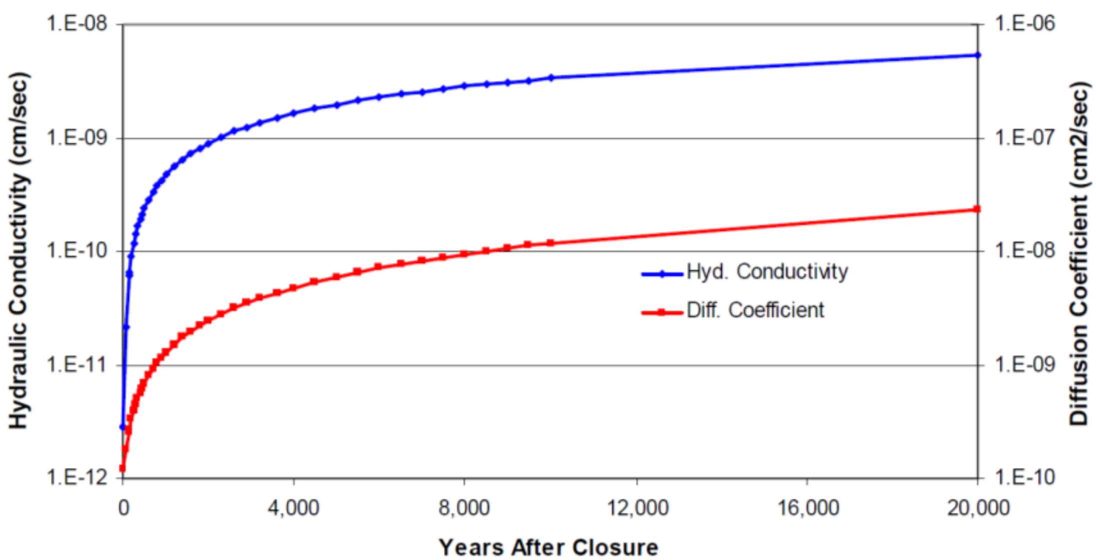

Figure 3: Hydraulic Conductivity and Diffusion Coefficient for the HDPE/GCL Composite Layer of the 150-foot Diameter Disposal Structures after Closure (Figure 4.2-19 in SRR-CWDA-2009-00017, Rev. 0)

The estimate of initial defects was based on the DOE quality assurance (QA) procedures for installing the HDPE layer. In the DOE document, SRNL-STI-2009-00115, Rev. 1, the DOE provided a description of the QA procedures that would be used for the HDPE in the HDPE/GCL composite layer above each disposal structure roof. Those procedures included industry-recommended procedures for avoiding wrinkles. In addition, the QA procedures include 100% visual inspection of seams and 100% non-destructive vacuum or air pressure testing of seams. The DOE also indicated that it would conduct periodic destructive testing of seams in accordance with industry standards and that the sites of destructive tests would be repaired and tested non-destructively after the repair. The DOE considered degradation of the HDPE layers by ultraviolet radiation, antioxidant depletion, thermal oxidation, high-energy irradiation, tensile stress cracking, attack from saltstone leachate, and biological degradation, including microbial action, root penetration, and effects of burrowing animals. Of those degradation mechanisms, the DOE concluded the mechanisms expected to cause the most degradation would be antioxidant depletion, thermal oxidation, and tensile stress cracking. Using the method in the 2004 Environment Agency of England and Wales Research and Development Technical Report P1-500/1/TR, the DOE estimated the creation of defects (i.e., pinholes, holes, tears, and cracks) in the closure cap HDPE from the combination of antioxidant depletion, thermal oxidation, and tensile stress.

The DOE expected the effects of other HDPE degradation mechanisms to be limited. The DOE identified several methods to limit high-energy-irradiation induced damage of the HDPE layers, including shielding, lowering the level of oxygen to which the HDPE layer is exposed, increasing antioxidant concentration in HDPE, use of a thicker HDPE layer, and minimizing tensile stresses on HDPE layers. Of those methods, the current DOE design is to use shielding (i.e., by the disposal structure walls), exposure to sub-surface (i.e., rather than atmospheric) oxygen concentrations, and thick (i.e., 2.5-mm [100-mil]) HDPE layer. The DOE indicated that little information was available on long-term degradation of HDPE by fungi or bacteria. However, the 1998 4th Edition of *Geosynthetics*, described HDPE as resistant to microbial degradation. The DOE also expected the 2.5 mm (100 mil) HDPE layer used to cover the disposal structures will be impervious to tree roots, except in areas with existing holes. As reported in the DOE document WSRC-STI-2007-00184, Rev. 2, that conclusion was based on U.S. Environmental Protection Agency and industry experience with HDPE geomembranes used in landfill applications indicating that tree roots are effectively stopped even by thinner HDPE layers (e.g., approximately 8 mm [30 mil]). The DOE also excluded the effects of burrowing animals from further consideration because the DOE expected that burrowing animals will be deterred by the overlying erosion barrier. Similarly, the DOE expected tree roots to be effectively deterred by the HDPE of the HDPE/GCL composite layer, and to cause GCL degradation only in areas of existing holes in the HDPE layer. In addition, the DOE expected the HDPE of the HDPE/GCL composite layer to prevent significant deterioration of the clay liner due to desiccation.

With respect to GCL degradation, the DOE considered the effects of slope stability, freeze-thaw cycles, dissolution, divalent cations (e.g., Ca^{+2}, Mg^{+2}), desiccation (wet-dry cycles), and biological degradation (e.g., root penetration, burrowing animals). Of those mechanisms, the DOE concluded that degradation by divalent cations was likely to cause the most significant effects on the GCL performance. Divalent cations can cause GCL degradation because the divalent cations replace two Na^{+} ions in the primary component of the GCL bentonite (i.e., sodium-montmorillonite). That replacement results initially in clays with approximately half the swelling capacity and poorer hydraulic conductivity, and subsequently in additional minerals that also have poorer hydraulic conductivity than sodium-montmorillonite. The DOE 2009 SDF PA included an assumption that the GCL degrades after the 100 year period of institutional controls (i.e., DOE assumed the sodium montmorillonite GCL to be converted to calcium or magnesium montmorillonite with a saturated hydraulic conductivity approximately one order of magnitude higher [5x10^{-8} cm/s]). The DOE used that hydraulic conductivity of the GCL in its determination of the hydraulic conductivity of the HDPE/GCL composite layer.

In the NRC 2012 SDF Technical Evaluation Report (TER) (ADAMS Accession No. ML121170309) the NRC concluded that the hydraulic properties assigned to the HDPE/GCL composite layers on the roof and under the floors, and the HDPE layer on the walls of the 150-Foot Diameter Disposal Structures appeared to be reasonable. The NRC evaluated the DOE consideration of potential sources of HDPE and GCL degradation and concluded that most major potential degradation modes were considered. The NRC also determined that the application of the methods that the DOE used to estimate antioxidant depletion were reasonable. With respect to estimation of the combination of the effects of antioxidant depletion, thermal oxidation and tensile stress cracking, in general, the NRC determined that the DOE application of the method in Technical Report P1-500/1/TR was reasonable. Although there was limited information about the effects of those chemicals on HDPE performance in the long-term (i.e., thousands of years), the NRC determined that the potential effects of those chemicals on the HDPE were accounted for, at least in part, by the DOE modeled degradation of HDPE hydraulic conductivity and diffusivity.

The NRC ended the evaluation in the 2012 TER by stating that " … the use of a material with which there is limited long-term engineering experience and no natural analogues, such as HDPE, introduces conceptual model uncertainty." The 2012 TER included the example that if the HDPE layer performs better than expected and forms few defects for thousands of years after placement, then the saltstone could oxidize substantially from gas-phase transport of oxygen while being exposed to very little water. If the HDPE layer were then to begin to fail several thousand years after placement, when the closure cover and disposal structure roofs may have degraded, then the oxidized saltstone could quickly be exposed to a sudden flow of water that could cause the release of a significant fraction of the Tc-99 inventory in a relatively short amount of time. Hypothetical sudden failures of the HDPE/GCL composite layer on the roof and under the floor of the disposal structures were expected to be mitigated to some extent by the GCL, which the NRC indicated could be expected to fail more gradually. However, if both layers fail as the result of a disruptive event (e.g., an earthquake or formation of a sink), then water flow through the disposal structures could increase significantly in a relatively short time. Thus, information regarding the potential for sudden failure of the HDPE/GCL composite layers was deemed by the NRC in the 2012 TER to be important to an evaluation of predicted site performance.

LLDL

As described in the DOE 2009 SDF PA, the 0.6 m (2 ft) LLDL placed above the geotextile fabric will extend approximately 7.6 m (25 ft) from the disposal structure walls, draining infiltration water to the backfill material that will be placed adjacent to the disposal structures. The LLDL will be designed to divert infiltrating water away from the underlying disposal structures and transport the water beyond each disposal structure perimeter in conjunction with the underlying composite HDPE/GCL composite layer and to prevent perched water on top of the disposal structures. The hydraulic properties of the backfill layer above the drainage layer are not expected to change; however, over time colloidal clay will migrate with the water flux from the lower backfill layer to the underlying LLDL. That water flux-driven clay was modeled as accumulating in the LLDL from the bottom up. The thickness of the clay-filled portion was modeled as increasing with time, while the thickness of the unfilled portion was modeled as decreasing with time. Those changes will result in an overall decrease in the hydraulic conductivity and porosity of the LLDL; so that, after approximately 19,000 years, the hydraulic conductivity and porosity of the LLDL was estimated to be similar to those for the overlying backfill layer (see Table 1).

Table 1: Hydraulic Parameters for the LLDL
(Table 4.2-12 in SRR-CWDA-2009-00017, Rev. 0)

Time Period	Conductivity (cm/sec)	Porosity	Reference
Initially (Sand drainage layer)	5.0E-02 (vertical) 5.0E-02 (horizontal)	0.417	WSRC-STI-2008-00244
After 19,013 years (Backfill)	4.1E-05 (vertical) 7.6E-05 (horizontal)	0.35	SRNL-STI-2009-00115

Based on the analyses described in the DOE document WSRC-STI-2008-00244, Rev. 0, which was presented in the DOE document SRNL-STI-2009-00115, Rev. 1, Figure 4 below illustrates the decrease in the vertical hydraulic conductivity of the LLDL.

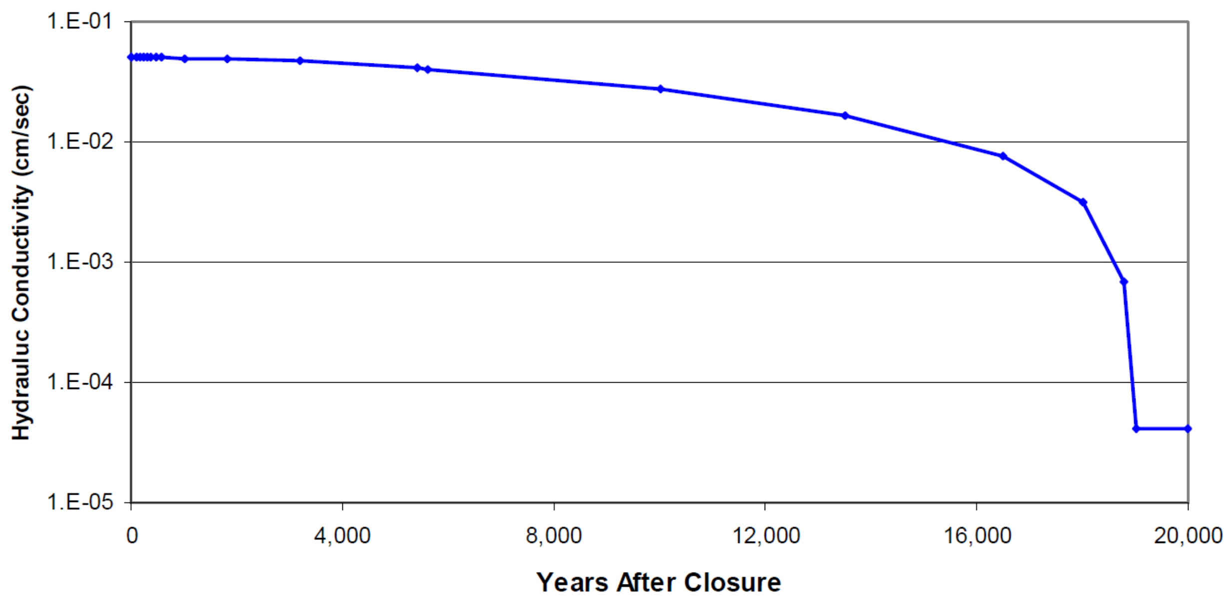

Figure 4: Vertical Hydraulic Conductivity of the LLDL
(Figure 4.2-15 in SRR-CWDA-2009-00017, Rev. 0)

The upper and lower lateral drainage layers are designed to divert a significant portion of the infiltrating water away from the underlying disposal structures. The DOE assumed that the degradation of the drainage layers (i.e., a reduction in hydraulic conductivity) will be controlled by colloidal infilling of the pore spaces within the drainage layers from the overlying backfill. As there is limited data regarding the service life of geotextile filter fabric holding back the particles and preventing the infilling, the NRC requested additional information about potential infilling of the drainage layers with larger particles and the resulting potential decrease in drainage layer hydraulic conductivity. In the DOE 2009 SDF PA, the DOE provided a model flow budget that showed that the LLDL significantly limits infiltrating water (e.g., approximately 99.9% of the water was modeled as being shed around the disposal structures at 10,000 years), although that assumption was changed in the subsequent DOE SDF FY 2013 and FY 2014 Special Analyses Documents. As described in the DOE document SRR-CWDA-2011-00044, Rev. 1, in response to RAI Comment PA-1, the DOE analysis indicated that the shedding of the water around the disposal structures was much more sensitive to assumptions about the disposal structure roofs and the HDPE/GCL composite layer above the disposal structures than it was to assumptions about drainage layer infilling. Specifically, for SDS 4, doubling the infilling of the drainage layers increased the Darcy velocity through saltstone by approximately a factor of three or less at 10,000 years in one of the cases. Although that is a relatively small increase, the NRC indicated that a factor of two to three difference in the Darcy velocity was more significant to the NRC assessing the DOE compliance with the performance objectives if predicted doses approach the relevant dose limit.

In the NRC 2012 SDF TER, the NRC questioned support for several assumptions in the DOE base case analysis. In the 2012 TER, the NRC determined that the DOE base case did not have an adequate technical basis to support the rate of infill for the LLDL and that the model support for both the geotextile filter fabrics and the lateral drainage layers was not commensurate with their expected long-term performance and risk significance.

Information in the FY 2013 Special Analysis Document (SRR-CWDA-2013-00062, Rev. 2) and the FY 2014 Special Analyses Document (SRR-CWDA-2014-00006, Rev. 2)

HDPE Layer and HDPE/GCL Composite Layer:
In the DOE SDF FY 2013 Special Analysis Document, the DOE indicated that to conservatively assess the performance of the HDPE layer and the HDPE/GCL composite layer, the initiation of the degradation of the 150-Foot Diameter Disposal Structure walls was assumed to occur after 900 years and the roofs and floors were assumed to begin to degrade after 1,400 years. Degradation of the concrete roof and walls was assumed to occur from carbonation and decalcification. Those times corresponded to the times that the modeled effectiveness of the HDPE layer and HDPE/GCL composite layer barriers was reduced by a factor of approximately 100. The increasing hydraulic conductivity values used to model the HDPE layer and the HDPE/GCL composite layer degradation over time are below in Table 2.

Table 2: Degradation of the HDPE Layer and HDPE/GCL Composite Layer (Table 4.2-8 in SRR-CWDA-2013-00062, Rev. 2)

Time Period (years)	HDPE Hydraulic Conductivity		HDPE-GCL Hydraulic Conductivity	
	Value (cm/s)	Ratio to Initial Value	Value (cm/s)	Ratio to Initial Value
0 - 50	5.87E-10	1	2.19E-11	1
900 – 1,000	6.04E-08	103	1.50E-09	68.5
1,400 – 1,600	9.69E-08	165	2.31E-09	105
9,500 – 10,000	6.44E-07	1,097	1.09E-08	498

As the DOE indicated in the FY 2013 Special Analysis Document, and re-indicated by the DOE in the FY 2014 Special Analysis Document for the 150-Foot Diameter Disposal Structures, carbonation and decalcification of the disposal structure cementitious materials was modeled by the DOE to initiate after 900 years for the HDPE layer only and 1,400 years for the combined HDPE/GCL composite layer in both the 150-Foot Diameter Disposal Structures and the 375-Foot Diameter Disposal Structures (i.e., corresponding to the time that the effectiveness of the HDPE and HDPE/GCL barriers were reduced by a factor of approximately 100). Similarly, the carbonation and decalcification of the roof and floor of the 375-Foot Diameter Disposal Structures was delayed by 1,400 years due to the performance of the HDPE/GCL composite layer. The hydraulic conductivity values used to model the HDPE layer and the HDPE/GCL composite layer degradation over time were the same as those above in Table 2.

LLDL:
Both the DOE SDF FY 2013 Special Analysis Document and the DOE SDF FY 2014 Special Analysis Document described the decreasing hydraulic conductivity of the sand unit within the LLDL as being controlled by the assumed annual precipitation rate and the associated sediment load. The process of filling in with fine-grained sediment (e.g., migration of colloidal clay) was filling in sediment modeled by the DOE with three different precipitation and infiltration rates. Figure 5 below illustrates the degradation of the LLDL using the different infiltration rates based on the model presented in the DOE document WSRC-STI-2008-00244, Rev. 0. The maximum, average, and minimum infiltration rates and degradation of the LLDL were used in the various flow cases being considered in the FY 2014 Special Analysis Document (e.g., the evaluation case used the average values).

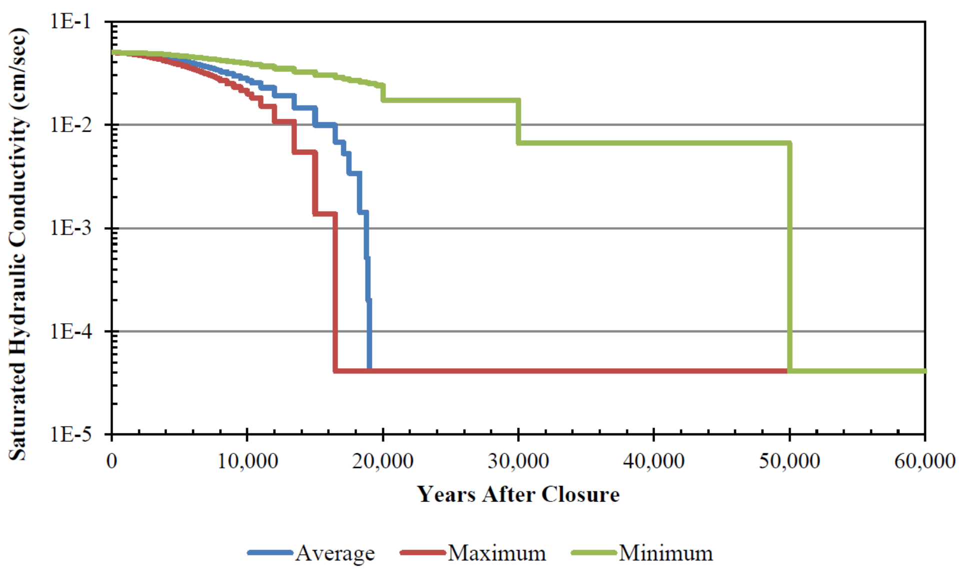

Figure 5: Hydraulic Conductivities of the LLDL for the 375-Foot Diameter Disposal Structures (Figure 3.3-9 in SRR-CWDA-2014-00006, Rev. 2)

Due to the increased degradation of the HDPE/GCL composite layer simulated in both the FY 2013 and FY 2014 Special Analysis Documents, around 1,400 years after closure the amount of water flowing through that composite layer and the salt wasteform below increases. Consequently, the amount of water being diverted around the wasteform within the LLDL would be expected to go down. However, as data compiled by the NRC staff from the PORFLOW model files illustrates in Figure 6, the amount of water being shed was still a significant portion of the overall infiltration that made its way through the engineered cover. Even after 10,000 years, the proportion of infiltrating water not flowing through the wasteform in a 375-Foot Diameter Disposal Structure was greater than 65% and the proportion not flowing through the wasteform in a 150-Foot Diameter Disposal Structure was greater than 90%. Because there were several barriers acting in series (e.g., LLDL, roof, saltstone), the contribution from individual barriers to that shedding is not clear to the NRC staff.

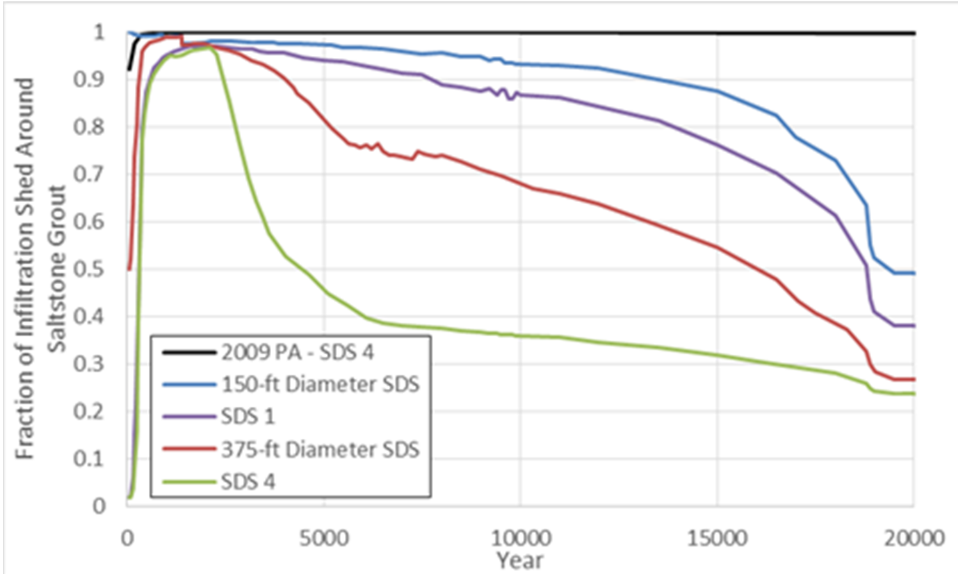

Figure 6: Fraction of Infiltration Shed Through the LLDL of the Various Disposal Structure Types (Adapted by NRC from the PORFLOW Model Files for the Evaluation Case in SRR-CWDA-2014-00006, Rev. 2)

NRC Evaluation

The NRC staff reviewed the DOE SDF FY 2014 Special Analysis Document and documented those technical topics that needed additional clarification or explanation in RAI Questions (ADAMS Accession No. ML15161A541). RAI Question Disposal Structure Performance (DSP)-8 was about the parameters used by the DOE to develop the flow cases and the criteria and basis used for selecting the three initial parameters that were varied to develop the sampling set of 18 flow cases. The DOE provided some responses to RAI Question DSP-8, but it is still not clear to the NRC how the DOE determined that the volumetric flow rates were not sensitive to HDPE/GCL degradation and how the DOE determined the hydraulic properties of the adjacent backfill.

HDPE Layer and HDPE/GCL Composite Layers:
In the NRC 2012 SDF TER, the NRC concluded that the hydraulic properties assigned to the HDPE/GCL composite layer on the saltstone disposal structure roofs and under the disposal structures floors and the HDPE on the disposal structures walls appeared to be reasonable. The NRC evaluated the DOE description of potential sources of HDPE and GCL degradation and concluded most major potential degradation modes were considered, although the NRC had remaining concerns about the potential effect on HDPE/GCL composite layer performance of soft zone consolidation and differential settlement. After 2012, liquid was observed in the SDS 3A liquid collection box. Although the liquid was periodically removed, the collection box continued to recharge with water. The DOE assumed that the liquid was rainwater from the surrounding soils that found a pathway through the HDPE layer and into the collection sump. Conditions that allow early flow through the system, such as a breach in the HDPE layer, are not consistent with either the DOE 2009 SDF PA or the DOE SDF FY 2013 Special Analysis Document or the DOE SDF FY 2014 Special Analysis Document. While reviewing the FY 2013 Special Analysis Document, the NRC issued RAI Comments to DOE, including RAI Comment DSP-1 that described concerns related to observations of water in the leak detection system of

SDS 3A. The leaks undermine the technical basis for the HDPE layer acting as a long-term barrier to liquid and gas. As described in the 2002 U.S. Environmental Protection Agency Report EPA/600/R-02/099, the NRC understands that sumps represent unique challenges for liner systems with their relatively unusual welds and the pipe penetration, as described in the DOE document SRR-CWDA-2014-00070, Rev. 0. However, the DOE has not yet determined how the water entered the SDS 3A leak detection system. The presence of water in that leak detection system could be due to relatively unusual welds and/or penetrations, but the leak was also consistent with the failure of the HDPE material or an HDPE seam. Because of the unique environmental conditions and construction practices encountered at each disposal structure, the NRC heavily considers direct evidence, such as the in-leakage in SDS 3A leak detection system, when evaluating whether the DOE disposal actions meet the performance objectives in 10 CFR Part 61. It is not clear to the NRC that the DOE support for assumptions related to the long-term performance of HDPE layer adequately accounts for location-specific conditions, such as the full range of relevant environment conditions, multiple and coupled degradation mechanisms, and actual construction practices.

In response to the NRC RAI Comment DSP-1 on the FY 2013 Special Analysis Document, in the DOE document SRR-CWDA-2014-00099, Rev. 1, the DOE described that by conservatively assuming the HDPE layer is not present in the model, the modeled processes of flow, degradation, and release would occur earlier in time and the DOE conclusions would not be adversely impacted. However, in the NRC RAI Question DSP-1 on the FY 2014 Special Analysis Document, the NRC described that the DOE analysis did not consider the potential impact of a breach in the HDPE layer in the closure cap or immediately below the sand drainage layer. In the DOE document SRR-CWDA-2016-00004, Rev. 1, the DOE provided an analysis in response to NRC RAI Question Saltstone Performance-5 with increased infiltration and removed the delay to saltstone degradation. The peak doses in that DOE analysis were shifted somewhat earlier in time, but the magnitude of the doses remained largely unchanged. Although such a sensitivity run is a good way to demonstrate the effect of a feature for one case run for a particular time period, the DOE has not clearly indicated if the technical basis for the overall expected performance of the HDPE layer and HDPE/GCL composite layer, which were documented in WSRC-STI-2007-00184, Rev. 2, WSRC-STI-2008-00244, Rev. 0, and supporting documents, has changed due to the potential breach of the SDS 3A HDPE. If the assumed HDPE and HDPE/GCL performance as modeled in both the FY 2013 and FY 2014 Special Analysis Documents is now the expected DOE performance, then the NRC expects that the DOE will revise the technical basis documents. If the technical basis for HDPE and HDPE/GCL performance has not changed since the supporting documents were issued, then the NRC expects that the DOE would revise the technical justification to indicate how and why the potential breach of the SDS 3A HDPE did not change the projected overall HDPE and HDPE/GCL performance. For example, if future DOE test results and analyses provide support, a technical basis may be updated with SDS 3A information that demonstrates that type of HDPE breach was prone to occur at only a few locations and that the overall effect on HDPE performance is not significant. The NRC will continue to review research related to HDPE/GCL composite layer performance, especially for SDF field-emplaced HDPE.

The DOE Response to NRC RAI Question DSP-8 in SRR-CWDA-2016-00004, Rev. 1 for the HDPE/GCL composite layer degradation parameter example discussed above prompted a Follow-Up Action Item during the NRC April 2016 SDF Onsite Observation Visit. Additional information in the DOE document SRR-CWDA-2016-00060, Rev. 0 was provided to the NRC to close that Follow-Up Action Item that clarified how the HDPE layer and HDPE/GCL composite layer had been modeled in both the FY 2013 Special Analysis Document and the FY 2014 Special Analysis Document. The DOE response to the Follow-Up Action Item in the DOE document SRR-CWDA-2016-00060, Rev. 0 described that past documents and model input discussions had not clearly differentiated between "what is expected" (i.e., long term resistance to flow) versus "what is assumed/modeled" (i.e., relatively short term degradation), which reflect two very different conditions." Tables 4.2-8 from both the FY 2013 Special Analysis Document and the FY 2014 Special Analysis Document (see Table 2 above) and the description in the DOE Response to NRC RAI Question DSP-11a on the FY 2014 Special Analysis Document showed the long-term resistance to flow as the DOE expected, but not as the DOE modeled. The hydraulic conductivity values used to simulate the HDPE layer and HDPE/GCL composite layer in the DOE PORFLOW model were not the same as the values given in Tables 4.2-8 from both the FY 2013 Special Analysis Document and the FY 2014 Special Analysis Document. The DOE information provided to close the Follow-Up Action Item from the NRC April 2016 SDF OOV provided the hydraulic conductivity values used to simulate the HDPE layer and HDPE/GCL composite layer (see Figure 7 below). Those values corresponded to the term "degraded" as used in both the FY 2013 and FY 2014 Special Analysis Documents.

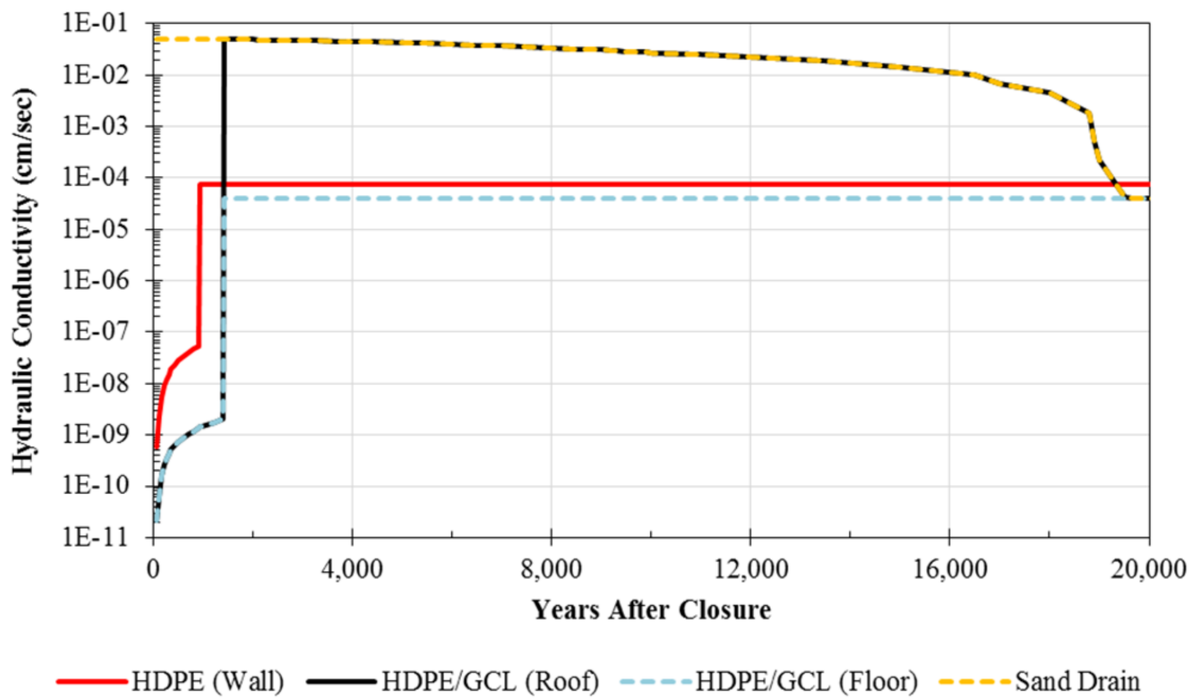

Figure 7: Hydraulic Conductivities of the HDPE Layer and HDPE/GCL Composite Layer after Closure as used in the Models for Both the DOE SDF FY 2013 and FY 2014 Special Analysis Documents (Figure AI 14-2 in SRR-CWDA-2016-00004, Rev. 1)

In the PORFLOW model in both the DOE SDF FY 2013 and FY 2014 Special Analysis Documents, the hydraulic conductivity of the wall HDPE in the 150-Foot Diameter Disposal Structures changes abruptly to a value similar to backfill at 900 years, while the roof HDPE/GCL was considered to behave like the overlying sand after 1,400 years. Since the hydraulic conductivity of the one-inch modeled HDPE/GCL composite layer is equivalent to that of the LLDL after that point-in-time, the values of the one-inch modeled HDPE/GCL composite layer were linked with that of the LLDL. As clay accumulated in the sandy LLDL, the properties of the one-inch modeled HDPE/GCL composite layer also changed and reflected the sand's transition to a clayey-sand, finally assuming backfill-like properties after 19,000 years. Similarly, the floor HDPE/GCL was considered to be fully degraded to backfill after 1,400 years (i.e., time when the effectiveness of the barrier was reduced by a factor of approximately 100). It is unclear to the NRC what the DOE technical basis was for the factor of 100 degradation of the HDPE layer and HDPE/GCL composite layer as the point for initiating degradation of the disposal structure concrete.

In models in both the FY 2013 and FY 2014 Special Analysis Documents, the HDPE hydraulic conductivity at the wall changed from $5x10^{-15}$ cm/s to $4x10^{-5}$ cm/s at 900 years and the HDPE/GCL hydraulic conductivity at the roof changed from $5x10^{-15}$ cm/s to $5x10^{-2}$ cm/s at 1,400 years. The DOE basis for the abrupt change in the modeled HDPE/GCL properties for the evaluation case in both Special Analysis Documents was that the degradation of those barriers must occur prior to the diffusion of carbon dioxide (from the soil) for degradation by carbonation, or degradation of concrete by decalcification. The DOE indicated that modeling abrupt failure of the HDPE layer and HDPE/GCL composite layer allowed the performance of the HDPE layer, HDPE/GCL composite layer, and both the 150-Foot Diameter and 375-Foot Diameter Disposal Structures to be better assessed.

While the NRC appreciates the DOE effort to begin simulating degradation processes earlier to observe the modeled effect on contaminant movement, the DOE conceptual model of the disposal system is now significantly different than what was presented in the DOE 2009 SDF PA. The technical bases for the expected performance of the HDPE layer and HDPE/GCL composite layer were documented in WSRC-STI-2007-00184, Rev. 2, WSRC-STI-2008-00244, Rev. 0, and supporting documents. The NRC evaluation of those DOE documents was documented in the NRC 2012 SDF TER. Although the models of the HDPE layer and HDPE/GCL composite layer sudden degradation after several hundred years in both the DOE SDF FY 2013 and FY 20134 Special Analysis Documents may be more conservative than the model in the PA, it is not clear to the NRC that the model will consistently be fully supported or conservative for all reasonably foreseeable circumstances and cases. Barrier performance could be obscured in PA sensitivity cases due to the temporal and spatial variability of possibly many processes and events affecting the performance a barrier and due to the redundancy of barriers where the potential performance of one barrier at a particular time may not be revealed due to the effectiveness of another barrier at that time.

By the DOE changing the original hydraulic properties of the HDPE/GCL composite layer to that of a sandy drainage layer, the modeled thickness of the LLDL increased from 12 in to 13 in. The one-inch thick model layer that impeded flow with a lateral hydraulic conductivity value of $5x10^{-15}$ cm/s then switched to promoting lateral flow with a hydraulic conductivity value of $5x10^{-2}$ cm/s. The changes to the hydraulic regime of a 375-Foot Diameter Disposal Structure is shown in both Figure 8 and Figure 9 below with PORFLOW vertical cross-sections of pressure heads before and after 1,400 years. The differences shown between Figure 9 and Figure 10 below are due to the changing properties of the underlying cementitious materials among other degradation processes.

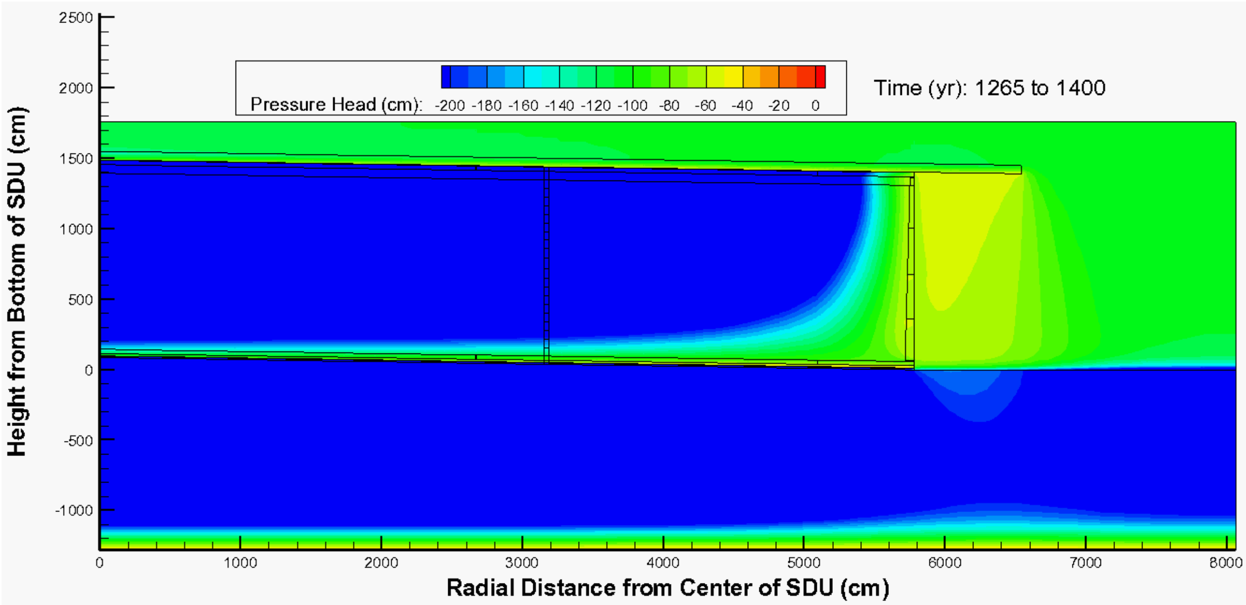

Figure 8: Pressure Head at Time 1,265 Years to 1,400 Years for a 375-Foot Diameter Disposal Structure Cross Section (Video File "SDU6_Flow_PressureHead.avi"in SRR-CWDA-2016-00060, Rev. 0)

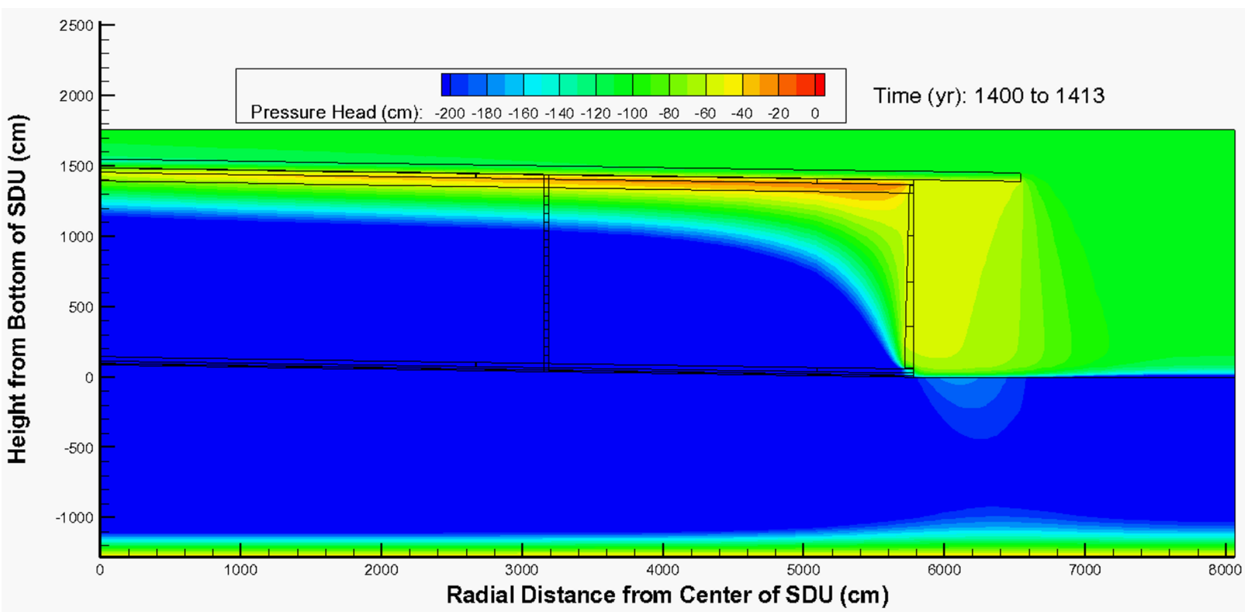

Figure 9: Pressure Head at Time 1,400 Years to 1,413 Years for a 375-Foot Diameter Disposal Structure Cross Section (Video File "SDU6_Flow_PressureHead.avi" in SRR-CWDA-2016-00060, Rev. 0)

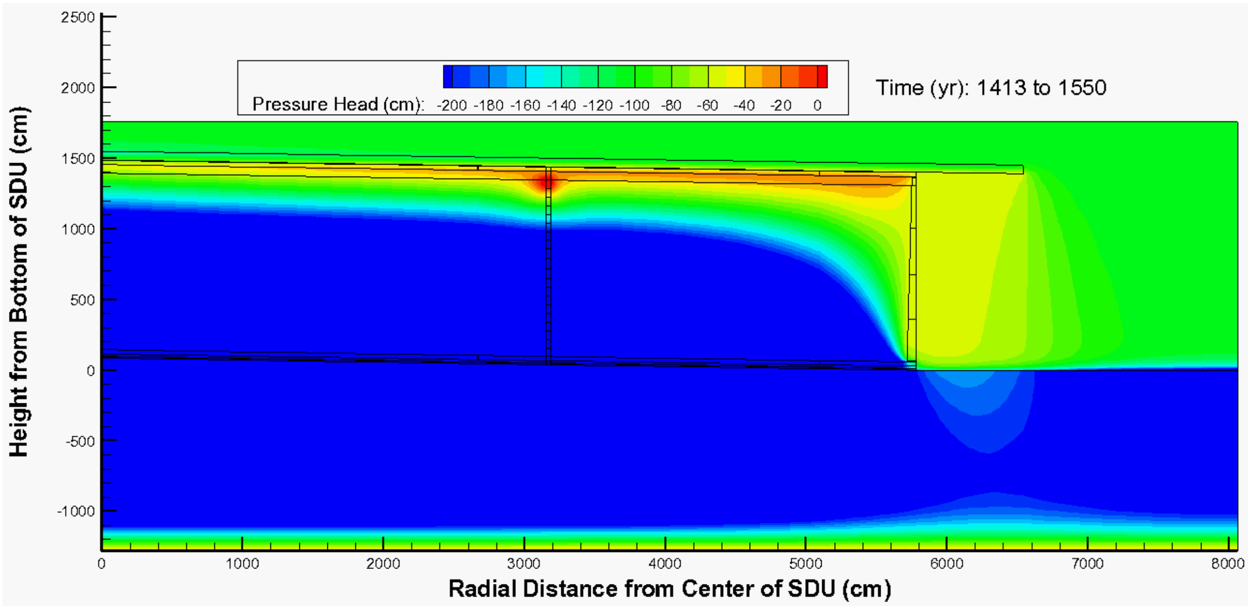

Figure 10: Pressure Head at Time 1,413 Years to 1,550 Years for a 375-Foot Diameter Disposal Structure Cross Section (Video File "SDU6_Flow_PressureHead.avi" in SRR-CWDA-2016-00060, Rev. 0)

Flow in and through the floor was also considerably changed in the year the HDPE/GCL composite layer was modeled as failing. Both Figure 11 and Figure 12 below show flow moving laterally toward the sides of the wasteform, while immediately after 1,400 years, water was modeled as flowing out of the bottom of the wasteform, thereby, potentially changing the location and concentration of a plume.

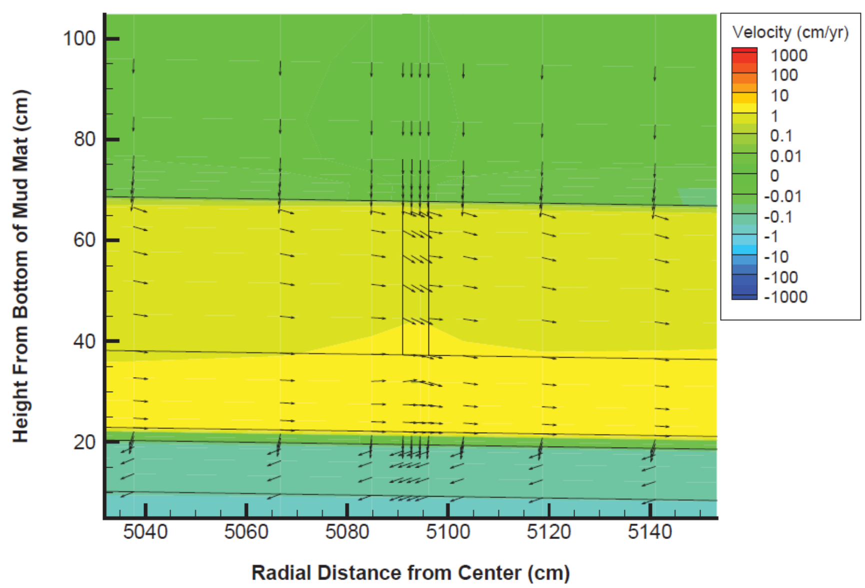

Figure 11: Flow Direction at Time 1,265 Years to 1,400 Years Through a Disposal Structure Floor (Figure CC-1.20 in SRR-CWDA-2016-00004, Rev. 1)

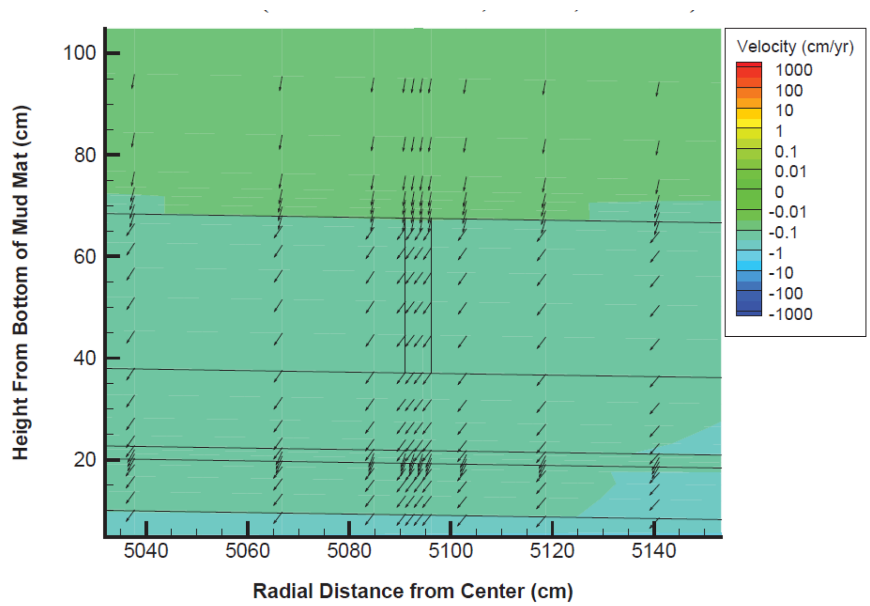

Figure 12: Flow Direction at Time 1,400 Years to 1413 Years Through a Disposal Structure Floor (Figure CC-1.21 in SRR-CWDA-2016-00004, Rev. 1)

Another example of potential performance being obscured due to the complexity and interdependencies of the system was previously discussed in the Background Section of this Technical Review Report (TRR). The NRC 2012 SDF TER had presented a hypothetical conceptual model where the HDPE layer performed better than expected so that the saltstone could substantially oxidize due to gas-phase transport of oxygen, while being exposed to very little water. If the HDPE layer were then to begin to fail suddenly several thousand years after placement, then the oxidized saltstone could quickly be exposed to a relatively sudden flow of water that could cause the release of contaminants in a relatively short amount of time.

The discussion above demonstrates that the PORFLOW model from the DOE 2009 SDF PA and the PORFLOW model from the DOE SDF FY 2014 Special Analysis Document represent two different conceptual models (i.e., what DOE expects versus what the DOE assumed). Although the current evaluation case in the FY 2014 Special Analysis Document assumed sudden and complete failure of the HDPE layer and HDPE/GCL composite layer performance after 900 and 1,400 years, respectively, the NRC staff is concerned that that model, which is not the DOE expected conceptual model, may not be fully supported or appropriate for all relevant time periods under different circumstances. Frequently, the difficulty of definitively establishing what feature or value is conservative is due to the complexity of the system and the interrelationships and interdependencies of many of the features and processes. The NRC staff recommends that both conceptual models (i.e., the evaluation case and the DOE expected or best estimate case) should be carried forward as sensitivity cases, so that insights can be gained.

LLDL:

The degradation assumptions of the HDPE layer and the HDPE/GCL composite layer in both the DOE SDF FY 2013 and FY 2014 Special Analysis Documents demonstrated the importance of the LLDL. In the PORFLOW model, the roof HDPE/GCL was considered to behave like the overlying sand after 1,400 years, and the floor HDPE/GCL was considered to be fully degraded to backfill at the end of 1,400 years. In the NRC 2012 SDF TER, the importance of the LLDL as a barrier together with the roof HDPE/GCL and the concrete roof was recognized. The NRC staff notes that even after the accelerated degradation rates had been implemented for two of those three barriers (i.e., HDPE/GCL composite layer, concrete roof), the LLDL was still modeled as diverting most of the infiltrating water away from a 375-Foot Diameter Disposal Structure, which allowed less than 35% of the available water to flow through the wasteform within the first 10,000 years (see Figure 6 above).

In the DOE document WSRC-STI-2008-00244, Rev. 0, the DOE described an analysis to determine the rate of clay deposition within the sand drain. Using the Hydrologic Evaluation of Landfill Performance (HELP) computer code, a model representing the future engineered cover was developed and documented in SRNL-STI-2009-00115, Rev. 1. That model was constructed to determine the amount of water flowing down from the bottom of the HDPE/GCL composite layer within the cover and was run for each time-step with degraded properties for each layer. Column 18 in Table 3 below shows the HDPE/GCL composite barrier saturated hydraulic conductivity for the infiltration estimates.

Table 3: Saturated Hydraulic Conductivity and Number of Holes in the HDPE/GCL Composite Layer (Table 23 in SRNL-STI-2009-00115, Rev. 1)

Based on WSRC-TR-2005-00101

(1) Stage	(2) Year	(3) Total Stage Hole Size (mm^2/ hectare)	(4) Total Cumulative Hole Size (mm^2/ hectare)	(5) Hole density (no./ hectare)	(6) Spacing (m)	(7) Fraction of HDPE membrane with Holes	(15) Ksat HDPE GCL (cm/s)	(16) Ksat hole GCL (cm/s)	(17) Ksat Liner (cm/s)	(18) Ksat Liner (cm/s)
							6.00E-13	7.50E-09	6.00E-13	2.81E-12
1	0	550	550	1	135	5.50E-08	6.00E-13	7.50E-09	6.00E-13	2.81E-12
2	2	0	550	1	135	5.50E-08	6.00E-13	7.50E-09	6.00E-13	2.81E-12
3	10	0	550	1	135	5.50E-08	6.00E-13	7.50E-09	6.27E-13	2.16E-11
4	90	35,750	36300	36	16.6	3.63E-06	6.00E-13	1.50E-07	1.91E-12	6.12E-11
5	140	51,000	87300	87	10.7	8.73E-06	6.00E-13	1.50E-07	2.04E-12	6.64E-11
6	150	8,730	96,030	96	10.20	9.60E-06	6.00E-13	1.50E-07	2.69E-12	9.17E-11
6	200	52,380	139,680	140	8.46	1.40E-05	6.00E-13	1.50E-07	3.35E-12	1.17E-10
6	250	96,030	183,330	183	7.39	1.83E-05	6.00E-13	1.50E-07	4.00E-12	1.42E-10
6	300	139,680	226,980	227	6.64	2.27E-05	6.00E-13	1.50E-07	4.66E-12	1.66E-10
6	350	183,330	270,630	271	6.08	2.71E-05	6.00E-13	1.50E-07	5.31E-12	1.91E-10
6	400	226,980	314,280	314	5.64	3.14E-05	6.00E-13	1.50E-07	5.97E-12	2.15E-10
6	450	270,630	357,930	358	5.29	3.58E-05	6.00E-13	1.50E-07	6.62E-12	2.39E-10
6	500	314,280	401,580	402	4.99	4.02E-05	6.00E-13	1.50E-07	7.93E-12	2.87E-10
6	600	401,580	488,880	489	4.52	4.89E-05	6.00E-13	1.50E-07	9.24E-12	3.34E-10
6	700	488,880	576,180	576	4.17	5.76E-05	6.00E-13	1.50E-07	1.05E-11	3.81E-10
6	800	576,180	663,480	663	3.88	6.63E-05	6.00E-13	1.50E-07	1.19E-11	4.27E-10
6	900	663,480	750,780	751	3.65	7.51E-05	6.00E-13	1.50E-07	1.32E-11	4.72E-10
6	1,000	750,780	838,080	838	3.45	8.38E-05	6.00E-13	1.50E-07	1.58E-11	5.62E-10
6	1,200	925,380	1,012,680	1013	3.14	1.01E-04	6.00E-13	1.50E-07	1.84E-11	6.50E-10
6	1,400	1,099,980	1,187,280	1187	2.90	1.19E-04	6.00E-13	1.50E-07	2.10E-11	7.35E-10
6	1,600	1,274,580	1,361,880	1362	2.71	1.36E-04	6.00E-13	1.50E-07	2.36E-11	8.19E-10
6	1,800	1,449,180	1,536,480	1536	2.55	1.54E-04	6.00E-13	1.50E-07	2.62E-11	9.01E-10
6	2,000	1,623,780	1,711,080	1711	2.42	1.71E-04	6.00E-13	1.50E-07	3.02E-11	1.02E-09
6	2,300	1,885,680	1,972,980	1973	2.25	1.97E-04	6.00E-13	1.50E-07	3.41E-11	1.14E-09
6	2,600	2,147,580	2,234,880	2235	2.12	2.23E-04	6.00E-13	1.50E-07	3.80E-11	1.25E-09
6	2,900	2,409,480	2,496,780	2497	2.00	2.50E-04	6.00E-13	1.50E-07	4.20E-11	1.36E-09
6	3,200	2,671,380	2,758,680	2759	1.90	2.76E-04	6.00E-13	1.50E-07	4.72E-11	1.51E-09
6	3,600	3,020,580	3,107,880	3108	1.79	3.11E-04	6.00E-13	1.50E-07	5.24E-11	1.65E-09
6	4,000	3,369,780	3,457,080	3457	1.70	3.46E-04	6.00E-13	1.50E-07	5.90E-11	1.81E-09
6	4,500	3,806,280	3,893,580	3894	1.60	3.89E-04	6.00E-13	1.50E-07	6.55E-11	1.97E-09
6	5,000	4,242,780	4,330,080	4330	1.52	4.33E-04	6.00E-13	1.50E-07	7.21E-11	2.13E-09
6	5,500	4,679,280	4,766,580	4767	1.45	4.77E-04	6.00E-13	1.50E-07	7.86E-11	2.28E-09
6	6,000	5,115,780	5,203,080	5203	1.39	5.20E-04	6.00E-13	1.50E-07	8.51E-11	2.43E-09
6	6,500	5,552,280	5,639,580	5640	1.33	5.64E-04	6.00E-13	1.50E-07	9.17E-11	2.57E-09
6	7,000	5,988,780	6,076,080	6076	1.28	6.08E-04	6.00E-13	1.50E-07	9.82E-11	2.71E-09
6	7,500	6,425,280	6,512,580	6513	1.24	6.51E-04	6.00E-13	1.50E-07	1.05E-10	2.84E-09
6	8,000	6,861,780	6,949,080	6949	1.20	6.95E-04	6.00E-13	1.50E-07	1.11E-10	2.97E-09
6	8,500	7,298,280	7,385,580	7386	1.16	7.39E-04	6.00E-13	1.50E-07	1.18E-10	3.10E-09
6	9,000	7,734,780	7,822,080	7822	1.13	7.82E-04	6.00E-13	1.50E-07	1.24E-10	3.22E-09
6	9,500	8,171,280	8,258,580	8259	1.10	8.26E-04	6.00E-13	1.50E-07	1.31E-10	3.34E-09
6	10,000	8,607,780	8,695,080	8695	1.07	8.70E-04	6.00E-13	1.50E-07	2.62E-10	5.34E-09
6	20,000	17,337,780	17,425,080	17425	0.76	1.74E-03	6.00E-13	1.50E-07	3.93E-10	6.86E-09
6	30,000	26,067,780	26,155,080	26155	0.62	2.62E-03	6.00E-13	1.50E-07	5.24E-10	8.13E-09
6	40,000	34,797,780	34,885,080	34885	0.54	3.49E-03	6.00E-13	1.50E-07	6.54E-10	9.24E-09
6	50,000	43,527,780	43,615,080	43615	0.48	4.36E-03	6.00E-13	1.50E-07	1.31E-09	1.35E-08
6	100,000	87,177,780	87,265,080	87265	0.34	8.73E-03	6.00E-13	1.50E-07	1.31E-08	4.41E-08
6	1,000,000	872,877,780	872,965,080	872965	0.11	8.73E-02				

The results from WSRC-STI-2008-00244, Rev. 0 and SRNL-STI-2009-00115, Rev. 1 were used in both the DOE SDF FY 2013 and FY 2014 Special Analysis Documents with a maximum, average, and minimum infiltration rate of 12.5 in/yr, 10.6 in/yr, and 5.4 in/yr (31.8 cm/yr, 26.9 cm/yr, and 13.7 cm/yr) at 10,000 years. As described above in this TRR, the engineered closure cap will contain a HDPE/GCL composite layer similar to the roof and floor HDPE/GCL composite layers with the exception that HDPE layer is somewhat thinner (1.5 mm vs. 2.5 mm) within the cover. Roof and floor HDPE/GCL composite layers were assumed to degrade at 1,400 years. However, for the HDPE/GCL composite layer within the surface cover, that abrupt degradation was not modeled and degradation was modeled at the gradual rate documented in the FY 2014 Special Analysis Document. That is counterintuitive to the NRC staff because the HDPE layer is thinner and the composite layer is closer to the surface so that the number of degradation processes should be greater. The NRC staff is aware that the DOE chose to degrade the modeled properties of the roof and floor HDPE/GCL in order to allow the performance of the HDPE and HDPE/GCL barriers in both the 150-Foot Diameter and 375-Foot Diameter Disposal Structures to be assessed.

The infiltration rate is important to the rate that the LLDL fill in or clog with fine-grained sediment because the infiltration rate determines the cumulative water volume flowing into each layer. In the model for the DOE SDF FY 2014 Special Analysis Document, the cumulative water volume over each square foot was multiplied by the colloidal clay concentration (i.e., 63 mg/L) to determine the amount of clay entering the sand layer for each time step (i.e., the infiltration rate was directly proportional to the rate of clogging). As discussed in the report on the NRC SDF OOV from April 19-21, 2016 (ADAMS Accession No. ML16147A197), due to the recent rainfall in the SRS area over the last few years, the infiltration rates used for the FY 2014 Special Analysis Document may be reevaluated and potentially increased in next revision of the DOE SDF PA. If that is the case, then the NRC staff recommends that the calculation for the filling in of the LLDL be reevaluated by the DOE because that process depends on the infiltration rate.

The NRC staff reviewed the DOE SDF FY 2014 Special Analysis Document and documented those technical topics that needed additional clarification or explanation in RAI Questions (ADAMS Accession No. ML15161A541). RAI Question DSP-15 related to the assumptions in the LLDL, as used in both the FY 2013 and FY 2014 Special Analysis Documents. One assumption from the FY 2014 Special Analysis Document was that the DOE anticipated that clay would move from the backfill and accumulate in the LLDL from the bottom-up to form a depositional layer at the bottom of the drainage layer similar to the formation of the B soil horizon. In the DOE response (SRR-CWDA-2016-00004, Rev. 1) to RAI Question DSP-15 the DOE provided soil literature references for a "bottom-up" accumulation of clays in the B horizon or subsoil, including *Soil Genesis and Classification* (1973), *Factors of Soil Formation: A System of Quantitative Pedology* (1994), and *Soil Genesis and Classification* (2011). Those references described the plugging of voids by clays in deeper soil horizons and the processes that cause clay to accumulate above the zones of lower permeability initiating the phenomenon of clay layer growth from the bottom up. In humid regions, B horizons are the layers of maximum accumulation of materials such as silicate clays, iron and aluminum oxides, and organic material. Those materials typically accumulate through a process termed illuviation, wherein the materials gradually wash in from the overlying horizons. However, it is not clear to the NRC staff if the accumulation of clays in the B Horizon can be used by the DOE as an analogue to the layers within the closure cap because the references described the pedogenic process, which is the process of soil formation in its natural environment. It is not clear to the NRC staff if the velocity of the water flowing laterally in the LLDL with a slope of 1.5% to 2.0% is sufficiently slow to allow the deposition of clay particles.

If soil formation or clay accumulation through illuviation can also occur in a layer intended to drain water, such as in a clean sand layer with a slope of 1.5% to 2.0%, then the definition of "bottom" may need to be reevaluated by the DOE. If the bottom was defined by the DOE as the lowest point within the disposal structure, then those areas of the LLDL that extend past the disposal structure would be the bottom because the slope is downward and away from the disposal structure. Because the LLDL slopes downward from the center of a disposal structure, the end of the LLDL towards the backfill lies deeper than the LLDL lying directly above the disposal structure roof. It is possible that the end of the LLDL could fill in first and completely clog that part of the layer where the top of a sand layer section is lower than the bottom of another sand layer section. Thus, at some point in time, the clogged sand layer would prevent water in the LLDL from being able to effectively drain into the backfill, which would allow more water into the disposal structure. It is also possible that the "deepest first" clogging process could proceed at such a slow rate that performance will not be significantly affected or the colloidal particles would not deposit at the LLDL–backfill-interface and drain into the underlying backfill. The DOE has not demonstrated that the conceptual model used in both the FY 2013

Special Analysis and FY 2014 Special Analysis Documents is fully supported or appropriate for all plausible scenarios.

Currently, the DOE assumes that the clay will uniformly deposit at the bottom of the entire length of the LLDL. That pattern of clay deposition will always leave an ever decreasing, but uniform, layer of sand without clay above an ever increasing layer of clay-clogged sand. The clean layer of sand allows the overall hydraulic conductivity of the combined sand /clay layer to remain relatively high. As described in the DOE documents SRR-CWDA-2016-00004, Rev. 1 and WSRC-TR-2003-00436, that equivalent hydraulic conductivity is determined by applying the following equation:

$$\text{Equivalent K} = (K_{filled} \times \text{Fraction of LLDL filled}) + (K_{clean} \times (1 - \text{Fraction of LLDL filled}))$$

where;
K_{filled} is the hydraulic conductivity of the bottom part of the LLDL that has filled in with sediments and
K_{clean} is the hydraulic conductivity of the top part of the LLDL that remains as clean sand.
Table 4 below contains the saturated hydraulic conductivity of the LLDL over time, which demonstrates the continued influence of the decreasing layer of sand on its effectiveness as a drainage layer:

Table 4: Saturated Hydraulic Conductivity of the LLDL over Time (Appendix I in WSRC-STI-2008-00244, Rev.)

Lower Drainage Layer Saturated Hydraulic Conductivity Over Time					
Year After Cap Construction	**K_{filled} (cm/s)**	**Fraction of LDL Filled**	**K_{clean} (cm/s)**	**1 - Fraction of LDL Filled**	**Hydraulic Conductivity (cm/s)**
0	4.1E-05	0.000	5.0E-02	1.000	5.000E-02
100	4.1E-05	0.000	5.0E-02	1.000	5.000E-02
180	4.1E-05	0.000	5.0E-02	1.000	5.000E-02
220	4.1E-05	0.000	5.0E-02	1.000	5.000E-02
300	4.1E-05	0.000	5.0E-02	1.000	5.000E-02
380	4.1E-05	0.000	5.0E-02	1.000	4.999E-02
460	4.1E-05	0.000	5.0E-02	1.000	4.998E-02
560	4.1E-05	0.001	5.0E-02	0.999	4.995E-02
1,000	4.1E-05	0.005	5.0E-02	0.995	4.974E-02
1,800	4.1E-05	0.020	5.0E-02	0.980	4.899E-02
3,200	4.1E-05	0.065	5.0E-02	0.935	4.676E-02
5,412	4.1E-05	0.175	5.0E-02	0.825	4.126E-02
5,600	4.1E-05	0.186	5.0E-02	0.814	4.069E-02
10,000	4.1E-05	0.453	5.0E-02	0.547	2.736E-02

LDL = Lower Drainage Layer; K_{filled} = Hydraulic Conductivity of clay-filled LDL; K_{clean} = Hydraulic Conductivity of non-clay-filled LDL

At 10,000 years, 45% of the sand layer has been filled in with clay; however, the overall equivalent hydraulic conductivity is only slightly reduced and is still characteristic of sand (2.7×10^{-2} cm/s). Alternative conceptual models may also be plausible, such as preferential flow through the soils allowing an uneven deposition of colloids to occur in the sand drain layer and reducing the overall equivalent hydraulic conductivity of the sand.

NRC Conclusions

In the NRC 2012 SDF TER, the NRC concluded that the hydraulic properties assigned to the HDPE/GCL composite layer on the saltstone disposal structures roofs and under the disposal structures floors and the HDPE on the disposal structure walls appeared to be reasonable. After 2012, a potential breach might have occurred in the SDS 3A HDPE. A sensitivity analysis for the current DOE evaluation case for such a breach demonstrated a shift in the time of contaminant release, but not in the magnitude. That analysis showed how a feature may affect performance in one case run under a particular set of conditions; however, it is not a substitute for the overall technical basis for the expected performance of that feature. The DOE has not clearly indicated if the technical basis for the overall expected performance of the HDPE layer and HDPE/GCL composite layer, as documented in WSRC-STI-2007-00184, Rev. 2, WSRC-STI-2008-00244, Rev. 0, and supporting documents, has changed due to the potential breach of the SDS 3A HDPE.

The NRC staff determined that the PORFLOW model from the DOE 2009 SDF PA and the PORFLOW model from the DOE SDF FY 2014 Special Analysis Document represent two different conceptual models (i.e., what DOE expects versus what DOE assumed) with regard to the hydraulic properties of the HDPE geomembrane and the GCL and the amount of water flowing through the wasteform. The NRC staff is concerned that the PORFLOW model in the FY 2014 Special Analysis Document may not be fully supported or appropriate for all relevant time periods under different circumstances. Frequently, the difficulty of definitively establishing what feature or value is conservative is due to the complexity of the system and the interrelationships and interdependencies of many of the features and processes. The NRC staff recommends that both conceptual models (i.e., the evaluation case and the DOE expected or best estimate case) be carried forward as sensitivity cases, so that insights can be gained.

The DOE considered the HDPE layer and HDPE/GCL composite layer to be fully degraded to backfill after 900 and 1,400 years, respectively, which is the time corresponding to when the effectiveness of the barrier was modeled as being reduced by a factor of approximately 100. It is unclear to the NRC staff what the DOE technical basis was for the factor of 100 degradation of the HDPE layer and HDPE/GCL composite layer as the point for initiating degradation of the disposal structure concrete.

The NRC staff determined that additional information is needed from the DOE about the criteria and basis for how the few parameters used to develop the sampling set of flow cases were selected. As described in RAI Question DSP-8 on the FY 2014 Special Analysis Document, it is not clear to the NRC staff how the DOE determined that the volumetric flow rates were not sensitive to HDPE/GCL composite layer degradation or to the hydraulic properties of the adjacent backfill.

The DOE technical basis for the accumulation of clay particles on the bottom of the LLDL relies on reference from the study of soils. It is not clear to the NRC staff if the accumulation of clays in the B Horizon can be used by the DOE as an analogue for the layers within the engineered surface cover because the references describe the pedogenic process that is the process of soil formation in its natural environment. In addition, the deposition of clay particles may not occur if the water is not tranquil and the velocity of the water flowing laterally in the LLDL is not slow enough. Alternative conceptual models may also be plausible, such as preferential flow through the soils allowing an uneven deposition of colloids to occur in the sand drain layer and reducing the overall equivalent hydraulic conductivity of the sand. The NRC staff recommends that the DOE further develop the technical basis for the current conceptual fill in or clogging model.

The infiltration rate is important for the modeling clogging of the LLDL because the infiltration rate determines the cumulative water volume flowing into each layer and the water flow determines the influx of colloids. Due to recent meteorological events, infiltration rates used for the FY 2014 Special Analysis Document may need to be reevaluated and used in next revision of the SDF PA. Correspondingly, the NRC staff recommends that the calculation for the filling in process of the LLDL be reevaluated by the DOE if the range of infiltration rates is revised.

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