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CONTAINMENT OF LOW-LEVEL RADIOACTIVE WASTE AT THE DOE SALTSTONE DISPOSAL FACILITY

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ABSTRACT

As facilities look for permanent storage of toxic materials, they are forced to address the long-term impacts to the environment as well as any individuals living in affected area. As these materials are stored underground, modeling of the contaminant transport through the ground is an essential part of the evaluation. The contaminant transport model must address the long-term degradation of the containment system as well as any movement of the contaminant through the soil and into the groundwater. In order for disposal facilities to meet their performance objectives, engineered and natural barriers are relied upon. Engineered barriers include things like the design of the disposal unit, while natural barriers include things like the depth of soil between the disposal unit and the water table. The Saltstone Disposal Facility (SDF) at the Savannah River Site (SRS) in South Carolina is an example of a waste disposal unit that must be evaluated over a timeframe of thousands of years. The engineered and natural barriers for the SDF allow it to meet its performance obejective over the long time frame.

INTRODUCTION

Disposal of low-level radioactive waste typically involves shallow land burial. Waste with suspect or trace contamination levels may be disposed without containment in a landfill-type facility. However, higher radionuclide concentrations, although still low-level, require an engineered containment system to ensure public safety for thousands of years into the future. One such example is the U.S. Department of Energy (DOE) Saltstone Disposal Facility (SDF) at the Savannah River Site (SRS) in South Carolina.

Liquid radioactive waste residing in storage tanks at the SRS is currently being removed and separated into a higher activity, lower volume, waste stream for vitrification and off-site disposal, and a lower activity, higher volume, stream for on-site disposal in the SDF. The latter aqueous salt waste is mixed with cement, fly ash, and ground blast furnace slag in a batch plant, and the resulting fresh grout poured into the SDF disposal units, where it becomes a solidified, cementitious, waste form called "saltstone". Each SDF unit is a subterranean engineered system composed of multiple barriers to waste release including low-permeability concrete, a waterproof epoxy coating, high-density polyethylene (HDPE), geo-synthetic clay liners (GCL), and a sand drainage layer. The engineered containment system is designed to prevent any significant radionuclide release in the near-term while radioactive attenuates shorter-lived nuclides, and provide for controlled release of longer-lived nuclides at a safe level over longer periods of at least 10,000 years. Once all SDF disposal units are filled, the overall facility will be covered with a low infiltration cap.

The SDF currently comprises a grout mixing plant and two existing rectangular concrete vaults or disposal units named Vault 1 and Vault 4. Future disposal capacity is planned in the form of cylindrical concrete tanks, the first pair of which is named Saltstone Disposal Unit (SDU) 2, comprising two disposal cells (tanks). Additional disposal cells will be grouped in sets of two or four tanks to form a disposal unit. Figure 1 illustrates the layout of existing and planned vault disposal cells. A total of sixty-four SDU-2 type cylindrical tanks are anticipated to meet Saltstone disposal requirements during a 30-year operational period.

Once buried and solidified, saltstone waste will not generally be directly accessible to the public. However, radionuclides may leach from the facility over the long-term and enter the groundwater where the future public could be exposed to contamination through drinking water and other scenarios. Thus, groundwater flow and contaminant transport modeling of the underground waste disposal facilities and surroundings is an essential part of evaluating the long-term impact to the environment from these toxic materials. The final impact will depend on the nature of the toxic material, e.g. half-life and retardation, as well as the nature of the disposal facility. Models must adapt to the specific requirements of the physical setup. The intent of this paper is to illustrate some typical elements that must be addressed in low-level radionuclide disposal by walking through an example groundwater pathway analysis.

COVER SYSTEM

One driver in the release of contaminants from a disposal cell is the amount of infiltration. Arid regions, with little average rainfall, would have a much lower starting infiltration than other regions such as the relatively humid Southeastern U.S. where the SDF is located . As a general rule, more infiltration will lead to contaminants moving more quickly through the soil. In addition, more water leads to more rapid deterioration of engineered structures. One method that is used to minimize the infiltration into a waste unit is to put a closure cap on top of it.

The planned SDF cover system is designed to physically stabilize the site, minimize infiltration, and deter potential site intruders. Jones and Phifer (2008) provide a detailed description of the conceptual design, and estimate infiltration and selected cap properties over a 10,000 year period of performance.

The closure cap is composed of the following layers: vegetative cover, topsoil, upper backfill, erosion barrier, geotextile fabric, middle backfill, geotextile filter fabric, upper lateral drainage layer, geotextile fabric, high density polyethylene (HDPE) geomembrane, geosynthetic clay liner (GCL), foundation layer, lower backfill, and lower drainage layer. The different layers are shown in Figure 2. These layers work in unison to limit the infiltration into the disposal units.

ENGINEERED CONTAINMENT BARRIERS

In addition to the engineered cover system, engineered containment features to minimize contaminant release to the natural environment are present in the disposal unit itself. As noted earlier, for the SDF the primary barriers are

1. Concrete enclosure - The primary SDF barrier is a concrete containment structure currently based on a commercial water tank design. The concrete mix is formulated to produce a low permeability (hydraulic conductivity of 1.e-10 cm/s or lower) and low effective diffusion coefficient (5.e-8 cm^2/s or lower). The mix also includes ground blast furnace slag to create a reducing environment, which most notably greatly retards Tc-99 mobility.
2. Waterproof interior coating - An epoxy coating is applied to the interior surfaces of the concrete containment structure to further hinder radionuclide leaching and protect the structure from chemical degradation.
3. HPDE liners - High-density polyethylene liners are placed outside the concrete roof, walls, and floor as an advection and diffusion barrier.
4. GCL liners - Similarly, geo-synthetic clay liners are placed under the floor concrete and above the roof to minimize water infiltration and contaminant leaching.
5. Sand drainage layer - A 2 ft thick layer of well-sorted sand is placed above the concrete roof to drain away soil infiltration that would otherwise tend to pond on the roof and increase water infiltration through the containment system.

These multiple barriers provide defense-in-depth with respect to radionuclide leaching to the natural environment outside the engineered containment system. The saltstone grout itself is another engineered barrier to waste release. Saltstone grout has a low hydraulic conductivity compared to surrounding soil, around 1.e-8 cm/s. Ground blast furnace slag in the dry mix leads to reducing conditions in the cured grout and effectively immobilizes Tc-99.

NATURAL BARRIERS

Since the main concern is typically with contaminants entering the groundwater, the distance between the bottom of the disposal unit and the aquifer can also have a significant impact on the impact to the environment. Different elements will have different rates of adsorption onto the soil. This will affect the rate at which the contaminant moves through the soil, i.e. retardation. For slow moving contaminants, a greater distance to the water table can have a dramatic impact on the time and size of the peak concentration in the aquifer zone. Furthermore, federal regulations allow for a 100-meter buffer zone around the SDF with respect to groundwater pathway exposure scenarios. Thus retardation in the both unsaturated and saturated zones is a natural barrier to future exposure.

MATERIAL DEGRADATION

Materials in the engineered disposal facility will undergo minimal degradation during the period of facility operation. However over longer time periods, 10,000 years or more, these features can be expected to undergo significant degradation. Thus, predictions of the long-term physical and chemical properties of these materials are essential to the groundwater model for the groundwater pathway analysis. The term "physical properties" refers to properties that result from the physical structure of the porous material, such as hydraulic conductivity, porosity, density, and effective diffusion coefficient. "Chemical properties" refers to attributes related to the chemistry of the material, such as sorption coefficient and reduction capacity.

As an example of physical degradation, the closure cap significantly reduces the amount of water flow when it is initially put in place, but after roughly 5,000 years, the cap will have degraded to a point where cap infiltration is only moderately slowed. Degradation in this case would develop through the following mechanisms (Jones and Phifer, 2008).

- vegetative succession from bahia grass to pine forest
- erosion of soil above the erosion barrier
- root penetration of the erosion barrier, lateral drainage, HDPE geomembrane and GCL layers
- antioxidant depletion, thermal oxidation, and tensile stress cracking of the HDPE geomembrane
- exposure of the GCL to divalent cations

Even more than the closure cap, the degradation of the saltstone material has a significant impact on the release of contaminants. A dominant mechanism for physical damage to Saltstone vault concrete is believed to be external sulfate attack. Sulfate is present in Saltstone feedwater and, after grout curing, remains at significant concentrations in pore water. Sulfate reaction with cement paste creates ettringite, an expansive mineral phase often associated with spalling or cracking. Estimates of degradation to vault hydraulic conductivity and diffusion coefficient from sulfate attack are needed for SDF performance assessment under a variety of scenarios and conditions. The concrete floor, walls, and roof are designed and predicted to retain most of their initial effectiveness as barriers well past 10,000 years, the designated period of performance for low-level waste disposals of this type. For the base case FDC, the material degradation is shown in Figure 3. As discussed, the impact from the closure cap is minimal after 5,000 years. The cementitious materials remain largely intact over this time period, with the wall showing the most degradation. The sand drainage layer also maintains most of its effectiveness past the 10,000 year compliance period.

In addition to physical degradation, chemical properties within the system will also change through time. Beyond the concrete and saltstone degradation processes discussed above, the mineral compositions of cementitious materials are expected to slowly change as water flows through pores and reacts with the solid matrices. Reduced materials will oxidize with exposure to dissolved oxygen in groundwater (increasing Eh), and pH will decrease as acidic groundwater dissolves the cement paste. These Eh and pH changes will affect sorption coefficients and generally increase the rate of contaminant transport. As an example of one of the impact this can have, Technetium is particularly sensitive to redox conditions, being practically insoluble at low Eh and relatively mobile under oxidized conditions. Reducing conditions in concrete and saltstone grout are projected to last well beyond the designated 10,000 year period of performance.

GROUNDWATER PATHWAY MODELS

The groundwater pathway analysis for the SDF was broken down into four sub-models. The vadose zone, extending down to the water table, was modeled separately from the aquifer zone. A flow and transport model was developed for each of these zones. The vadose zone is modeled separately from the aquifer zone due to the size difference with the relevant features. The vadose zone must address small engineered features of the disposal unit (e.g. a few inches of concrete) while the aquifer model by nature must cover the full 100-m compliance boundary. The scale difference makes a combined model computationally impractical. The model process for the SDF was to compute the vadose zone flow followed by the relevant contaminant transport. Since most of the disposal units had identical vadose zone geometries and inventory, a smaller number of vadose zone models were needed compared to the number of disposal units. To tie the vadose and aquifer models together, the flux from the vadose zone model was used as the source of the aquifer model.

PERFORMANCE CRITERIA

The performance requirements will depend on the nature of the toxic material and the governing regulatory requirements. As an example, for scoping assessments of Saltstone vault performance, groundwater concentrations were monitored at a distance of 100 meters from the facility boundary using the following criteria to measure impact:

- Environmental Protection Agency (EPA) Maximum Contaminant Levels (MCLs) http://www.epa.gov/safewater/contaminants/index.html, accessed 12/1/2008)
    - primary water standards for non-radionuclides, or secondary if no primary
    - 15 pCi/L for alpha-emitters
    - 4 mrem/yr for beta-emitters
    - 5 pCi/L for radium
    - 30 µg/L for uranium
- U.S. Department of Energy (DOE) 25 mrem/yr dose from water ingestion only

The period of performance after SDF facility closure is assumed to be 10,000 years.

PROJECTED FACILITY PERFORMANCE

Over a 10,000 year period of performance, Saltstone disposal cells are expected to degrade physically and chemically. Sulfate attack and slag oxidation are prominent examples of physical and chemical degradation, respectively. While some degradation, especially in the closure cap, is expected to occur, the system as a whole maintains much of its effectiveness. The engineered barriers meet their objective of minimizing contaminant transport. The final results from the analysis meet the performance objectives for the SDF.

CONCLUSION

Some waste disposal facilities are required to meet certain standards to ensure public safety. These type of facilities require an engineered containment system to ensure that these requirements are met. The Saltstone Disposal Facility (SDF) at the Savannah River Site (SRS) is an example of this type of facility. The facility is evaluated based on a groundwater pathway analysis which considers long-term changes to material properties due to physical and chemical degradation processes. The facility is able to meet these performance objectives due to the multiple engineered and natural barriers to contaminant migration.

REFERENCES

Jones, W. E. and M. A. Phifer. Saltstone Disposal Facility closure cap concept and infiltration estimates. WSRC-STI-2008-00244, Rev. 0. May 2008.

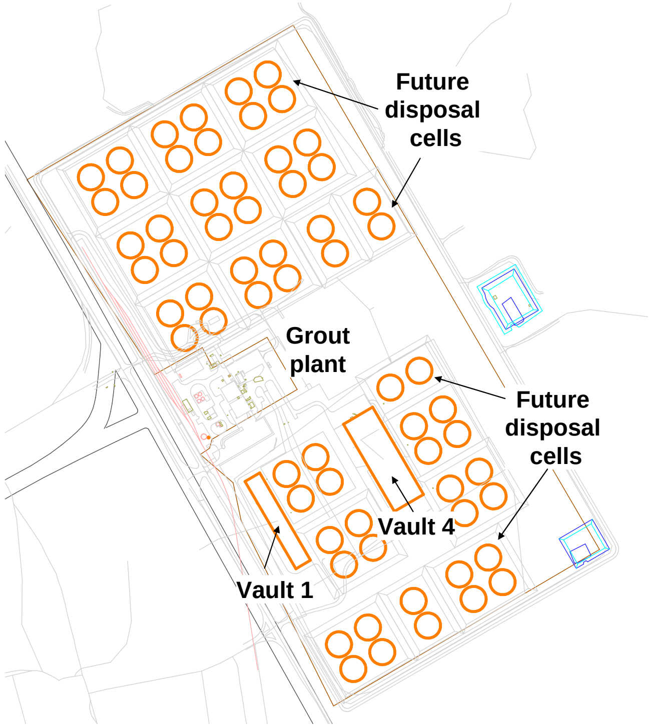

Figure 1. Disposal cell layout within the Saltstone Disposal Facility.

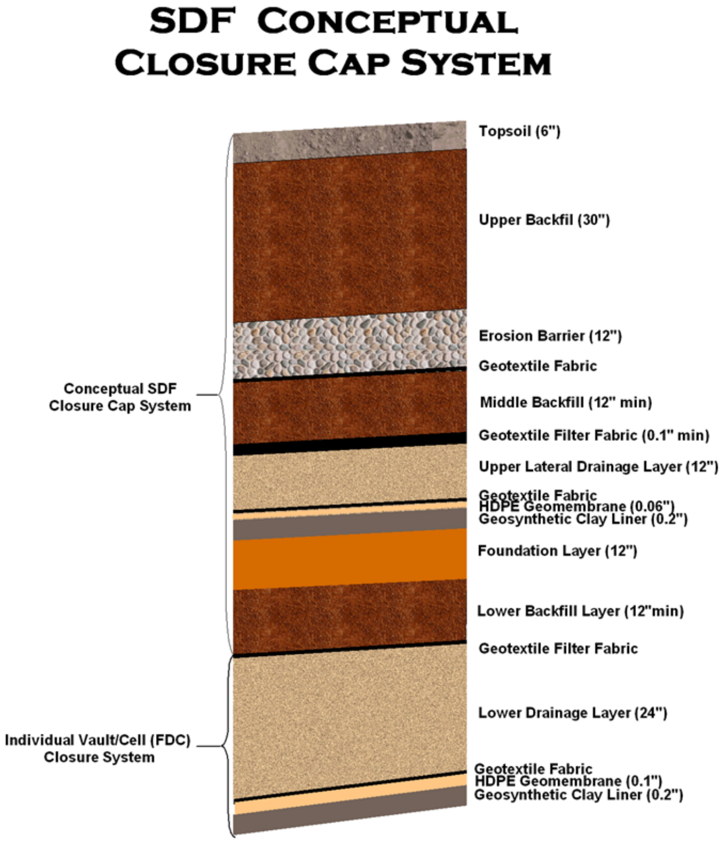

Figure 2. Layers composing the conceptual design of the SDF cover system.

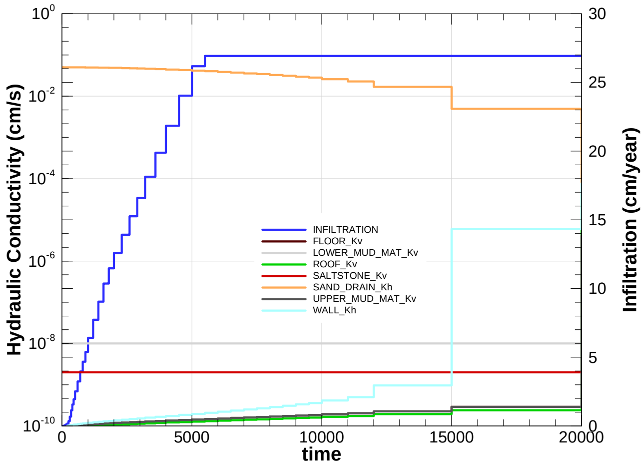

Figure 3. Engineered Systems through time.