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EFFECTS OF CLOSURE CAP AND LINER ON CONTAMINANT RELEASE RATES FROM GROUTED WASTES (U)

by

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Effects of Closure Cap and Liner on Contaminant Release Rates from Grouted Wastes

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ABSTRACT

This paper describes a groundwater modeling study of waste disposal concepts using grouted waste forms. The focus of the study is on the effects of clay caps and concrete vaults on contaminant migration. We modeled three waste disposal scenarios: 1) Grouted waste was solidified in an earthen trench and covered with soil. There was no vault and no cap. 2) Grouted waste was solidified in an earthen trench. The entire waste disposal facility was then closed under a clay cap. 3) Grouted waste was solidified in a concrete vault and protected by the same closure as in 2.

Because of the huge contrast in hydraulic conductivities and highly non-linear multi-phase flow characteristics, these waste disposal concepts presented a difficult problem for numerical simulation. Advanced fluid flow and contaminant transport codes were used to solve the problem. Among the codes tested, ECLIPSE [Intera 1993, Zhou 1994] out-performed other codes in speed, accuracy (smaller material balance errors) and capability in handling sophisticated scenarios.

We used nitrate as a tracer for the simulation. Nitrate does not absorb in the solid phase and does not decay. As a result, predicted release rate based on nitrate is conservative. We also assumed that the facility is intact for 10,000 years. In other words, properties of the materials used for this study do not change with time. We predicted the fraction of initial amount of nitrate released to the water table as a function of time. Predicted peak flux for the no vault and no closure case was 5.8×10^{-4} per year at 12 years. If a clay cap was installed, predicted peak flux was 8.5×10^{-5} per year at 110 years. If the grout was disposed in a concrete vault and covered by a clay cap, predicted peak flux became 4.4×10^{-6} per year at 8,000 years. Both concrete liner and clay cap can reduce the rate of contaminant release to the water table and delay the peak time.

The focus of this study is on groundwater protection. We assessed the performance of three unsaturated zone waste disposal concepts. Since unsaturated zone performance relied almost entirely on the properties of the waste form, the liner and the closure, these predictions are generic. For a site-specific performance assessment (PA) and design of waste disposal facility, we need to factor in 1) inventory, 2) alternative liners such as polymer and geotextile membranes, 3) degradation histories of waste form, liner and closure, 4) hydrogeological conditions, and 5) Cost.

INTRODUCTION

A field-scale grouted waste disposal program is being conducted at the Savannah River Site (SRS), a U.S. Department of Energy (DOE) facility in Aiken, South Carolina. At SRS, a low-level radioactive waste solution containing sodium nitrate, other dissolved solids, and trace radionuclides is mixed with slag, flyash, and cement to form a grout-like material called "Saltstone" [Langton 1988]. The grout is poured into concrete vaults constructed at the Saltstone Disposal Facility (SDF). The facility is designed for the release of contaminants in a slow, controlled manner over thousands of years. The impact of SDF on the environment was studied in a radiological PA [Westinghouse 1992]. The PA addresses the performance requirements and objectives mandated by DOE Order 5820.2A [U.S. DOE 1988]. One of the performance objectives is to show that the impacted groundwater will be in compliance with the Safe Drinking Water Act (SDWA) [U.S. DOE 1990].

Current Saltstone disposal concept includes a concrete vault, a clay/gravel drainage layer above the vault roof, and a clay/gravel closure cap over the entire facility. The bottom of the vault is at least 20 feet above the water table. Contaminants initially in the grouted waste form are released to the surrounding soil. For nitrate, the controlling release mechanisms are convection and diffusion. Dissolved contaminants in the unsaturated zone are carried to the water table by infiltrating water. Flow and transport in the aquifer system beneath the water table are simulated by a saturated zone model. The peak groundwater concentration at a compliance point is compared to the EPA drinking water maximum contaminant level (MCL) [U.S. EPA 1977]. The compliance point is anywhere in the aquifer that is more than 100 meters from the facility boundary. If the predicted peak concentration is less than its MCL for every contaminant, the disposal concept will be in compliance.

The modeling work was conducted in two parts, the unsaturated zone model and the saturated zone model. The unsaturated zone modeling domain was a two-dimensional vertical slice of the waste disposal facility above the water table. Figure 1 depicts the conceptual model and modeling grids used for the simulation. The unsaturated zone model predicted the nitrate mass flux (gram/year) released to the water table. This flux was divided by the initial inventory in the modeling domain to get the fractional release rate (year^{-1}). The nitrate release history was then used as the source term for the saturated zone model. The saturated zone model comprised the three-dimensional aquifer and aquitard system of concern. Flow and transport in the saturated zone depend heavily on site-specific hydrogeology. In contrast, flow and transport in the unsaturated zone depend mainly on properties of the materials use for the construction. Properties of the native and backfill soils are less important. SRS conducted a program to measure the physical properties of all materials used for this study [Westinghouse 1992]. In this paper, present only the unsaturated zone modeling work.

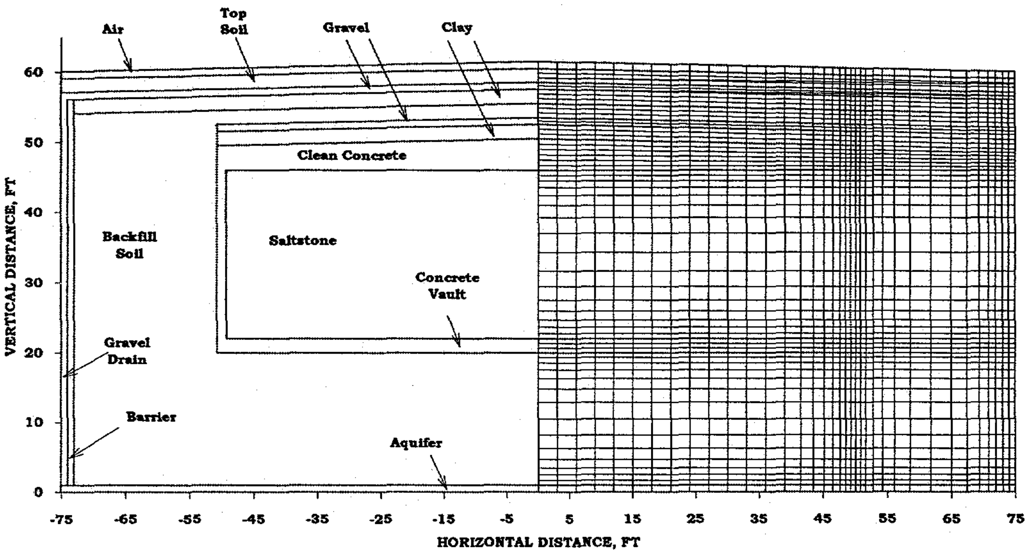

Figure 1. Saltstone conceptual model and modeling grid.

THE SALTSTONE DISPOSAL FACILITY

The SDF will consist of 15 concrete vaults. The first vault, completed in 1990, is 30.5-m wide by 183-m long by 7.6-m high (100 ft×600 ft×25 ft). It contains six 30.5 m × 30.5 m (100 ft×100 ft) cells. Thickness of the Saltstone vault bottom slab is 0.61 m (2 ft). The side walls are 0.46 m (1.5 ft) thick. The vaults will be filled with Saltstone up to 7.3 m (24 ft). A layer of clean concrete will then be poured above the Saltstone as the roof. The roof has a 2% slope and an average thickness of 0.61 m (2 ft). Prior to closure, the bottom of the vaults is at the ground level which is at least 6.1 m (20 ft) above the historical high water table.

After all the vaults are filled, the SDF will undergo closure. Current closure concept consists of the placement, from the top of the vault to the ground surface, of two feet of clay, one foot of gravel, two feet of backfill soil, two feet of clay, one foot of gravel, and two feet of top soil (Fig. 1). The purpose of the closure is to reduce infiltration, to prevent an inadvertent intruder from exposure to the waste, and to minimize the probability of waste exposure by erosion.

MODELING METHODOLOGY

A two-dimensional vertical cross-section of a Saltstone vault was modeled. The conceptual model and the grids used for the simulation are depicted in Figure 1. We modeled half of a vault to take advantage of symmetry. Initially, the Saltstone and the concrete vault were assumed to be saturated with water. The initial nitrate concentration in the Saltstone pore fluid was 0.16 g/cm^3.

Boundary conditions used for the simulation were: 1) constant water influx of 40 cm/yr at the top of the domain; 2) a 30 cm (1 ft) air layer at the top; 3) a 30 cm (1 ft) numerical aquifer layer at the bottom; 4) a vertical barrier and gravel drain at the side of the domain to remove run-off water from the clay cap; and, 5) zero convective and diffusive fluxes at the vertical boundaries due to symmetry. The 40 cm/yr water influx is the average infiltration rate at SRS. The air layer was maintained at 1.0 atmospheric pressure. The numerical aquifer was connected to a large aquifer to maintain a stable water table elevation.

RESULTS

The dominant mechanisms for nitrate release from the Saltstone are convection and diffusion. Convection results from a very small amount of water penetrating the vault and the waste form. Diffusion results from the concentration gradient between the Saltstone and the model boundaries. The relative importance between convection and diffusion is governed by the flow and transport properties of the porous media. The properties of the materials were assumed to remain unchanged during the entire modeled period. The hydraulic conductivities of and the nitrate diffusivities in the materials used for the simulation are shown in Table 1.

Table 1. Hydraulic conductivities and diffusivities.

Material	Hydraulic Conductivity (cm/sec)	Diffusivity (cm^2/sec)
Concrete	10^{-10}	10^{-8}
Saltstone	10^{-10}	5×10^{-9}
Top Soil	5×10^{-4}	5×10^{-6}
Backfill Soil	1.5×10^{-4}	5×10^{-6}
Native Soil	3×10^{-5}	5×10^{-6}
Gravel	10^{-1}	5×10^{-6}
Clay	10^{-7}	1.5×10^{-6}
Barrier	0.	0.

Contaminant transport also depends on the characteristics of the materials. The capillary pressure and aqueous-phase relative permeability curves used for the simulation are shown in Figures 2 and 3, respectively. Because of high capillary pressure, concrete and Saltstone remain at nearly 100% saturation. The other materials are less saturated. Reduced saturation results in lower effective permeability and lower diffusion rates.

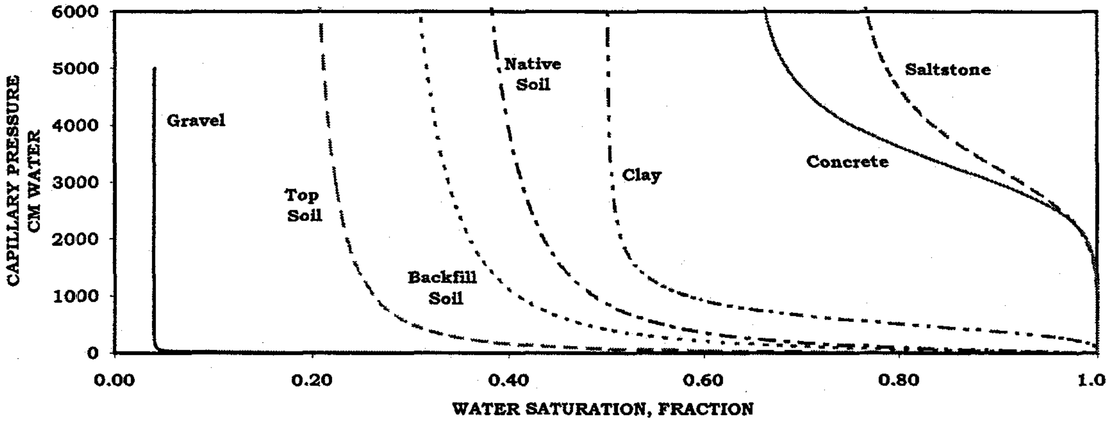

Figure 2. Capillary pressures.

The model predicted a history of nitrate mass flux (in grams/yr) recharged to the aquifer. This recharge rate was divided by the initial nitrate inventory in the modeling domain to obtain the fractional release rate (in yr^{-1}). Normalized flux histories for the three scenarios are depicted in Figure 4. Predicted peak fractional release rate for the no vault and no closure case was 5.8×10^{-4} per year at 12 years. If a clay cap was installed, predicted peak fractional release rate was 8.5×10^{-5} per year at 110 years. If the grout was disposed in a concrete vault and covered by a clay cap, predicted peak flux became 4.4×10^{-6} per year at 8,000 years.

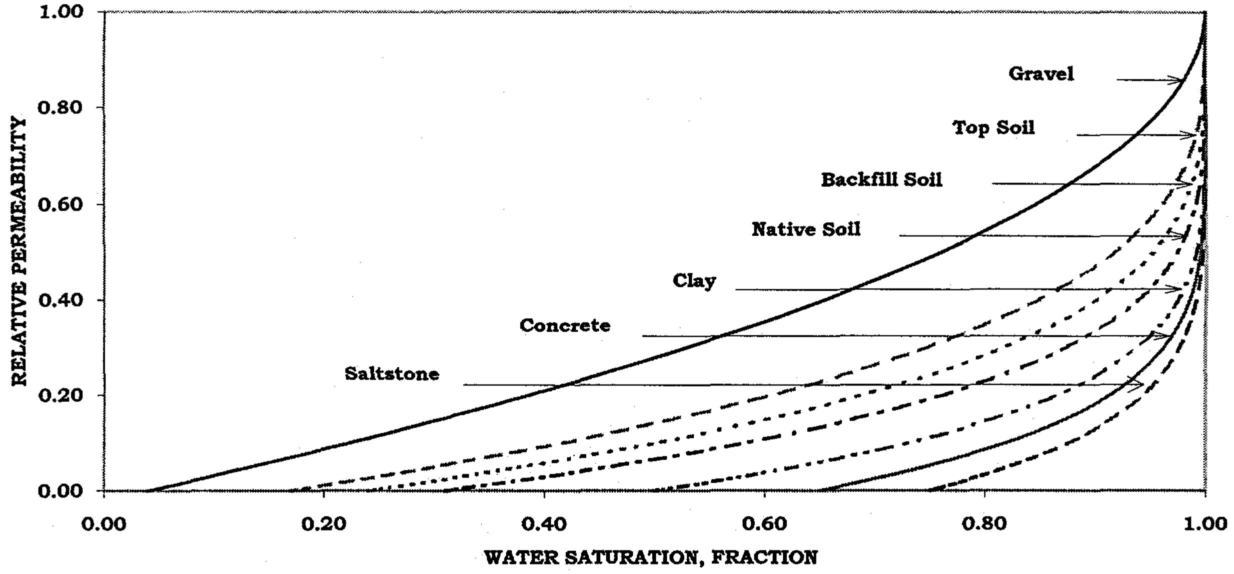

Figure 3. Aqueous-phase relative permeabilities.

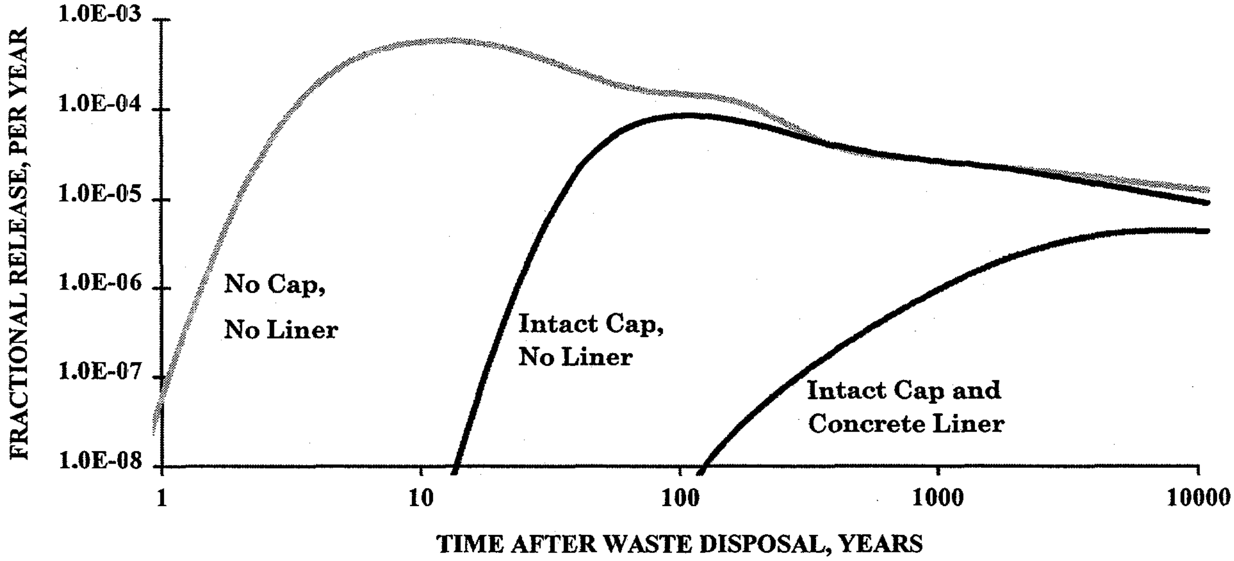

Figure 4. Predicted fractional release rates.

The cumulative nitrate release to the water table is shown in Figure 5. At the end of 10,000 years, 3.4% of nitrate was released to the aquifer for the intact liner, intact cap case. For the no liner case and the no liner, no cap case, it was 17% and 22%, respectively.

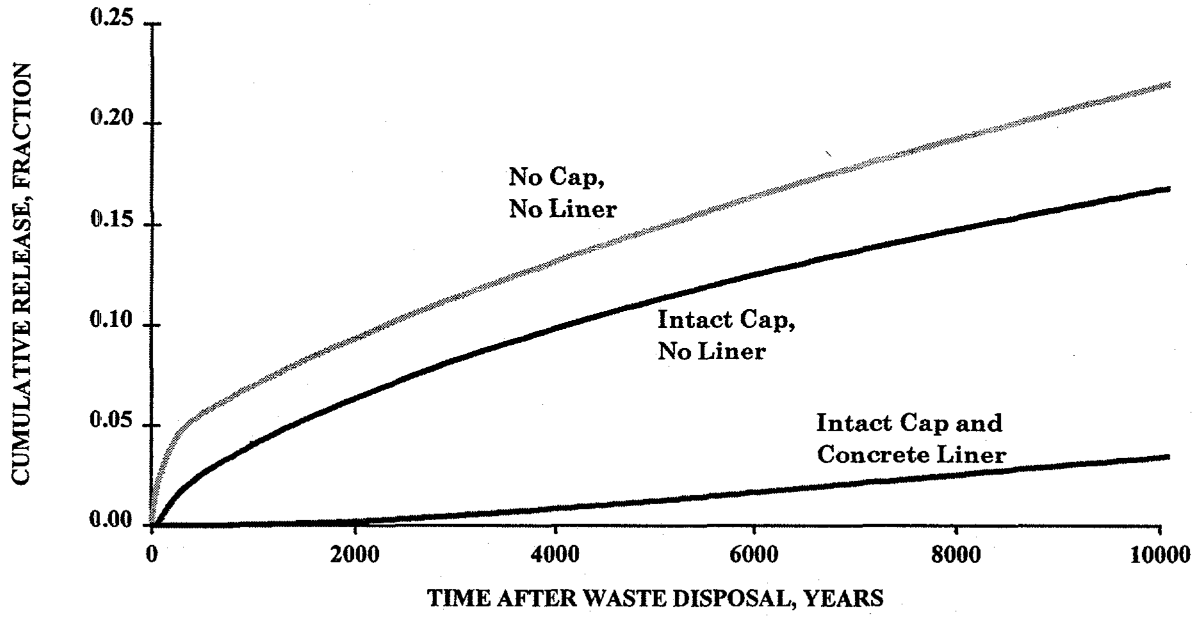

Figure 5. Predicted nitrate release to the water table.

DISCUSSION

The mechanisms of nitrate release are diffusion and convection. Because soil has relatively large diffusivity and permeability, the grout and the concrete vault control contaminant migration. The vault acts as a diffusion barrier between the waste and the surrounding soil. Without the vault, contaminants at their initial concentrations would be in direct contact with soil. This results in a quick and relatively large amount of contaminant release. With a vault, a slow build-up of concentration gradient across the vault wall must occur before nitrate could reach the soil. The convective release of nitrate depends primarily on the permeabilities of the liner and the grout. Because they are both 10^{-10} cm/sec, the liner would not slow downward flow velocity in the waste form. However, nitrate must penetrate the bottom slab of the vault before it is released to the soil. We estimated the delay time by $t = b\phi/v$, for which b is the bottom slab thickness (61 cm), ϕ is porosity (0.17), and v is the Darcy velocity. Modeled Darcy velocity in the vault was 3×10^{-3} cm/year. The bottom slab could delay convective transport by 3,500 years assuming plug flow. In the model, dispersion and concomitant diffusion made nitrate breakthrough earlier.

The groundwater performance objective is to comply with the drinking water maximum contaminant level (MCL) [EPA 1977]. The MCL for nitrate is 45 mg/liter. Based on our saturated zone modeling, the predicted maximum concentration at the compliance point is roughly proportional to the peak flux to the water table. For the no vault, no cap case, we predicted a peak mass flux of 5.8×10^{-4} per year at 12 years after waste disposal. As discussed earlier, an early release of nitrate resulted from diffusion. This was the worst scenario assuming no barrier other than the waste form itself.

For the no vault, intact cap case, we assumed the permeability of the cap to be 10^{-7} cm/sec, which was a conservative value used for clay. The closure reduced water infiltration from 40 to 3 cm/year. Predicted peak flux was 8.5×10^{-5} per year at 110 years, which improved the performance by a factor of seven over the no vault, no cap case.

For the intact vault, intact closure case, we predicted a peak flux of 4.4×10^{-6} per year at 8,000 years, which was more than 100 times improvement over the no vault, no cap case. Concrete liners not only reduced the peak flux but also delayed nitrate release by thousands of years.

In this study, we assumed the properties of the waste form, the liner, and the closure to be constant. In reality, these engineered materials would degrade with time. As a result, predicted long-term performance was optimistic. However, predicted short-term performance was conservative because we used conservative material properties and degradation could be neglected. The no vault and no cap case was the worst scenario for the grout disposal concept. If a site-specific PA predicted compliance with this waste disposal concept, there would be no need for liner and closure.

The closure cap enhances groundwater protection by a factor of seven. It also protects against intruders and erosion. We predicted a peak nitrate flux of 8.5×10^{-5} per year for the intact closure, no liner case. For absorbing and/or decaying contaminants such as radionuclides, the release rates could be smaller. If we could construct a more effective closure, we could further reduce the nitrate flux.

The concrete vault acts primarily as a diffusion barrier in the first 150 years after waste disposal. However, vault construction is the major project cost for SDF, at approximately 18 million dollars per vault. It is conceivable that we can replace the concrete liner with lower cost polymer or geotextile liners and still achieve adequate performance. SRS is looking into these alternatives.

We assumed that the properties of all materials to be constant up to 10,000 years. In our future analysis, we will include degradation scenarios of the waste form, the liner, and the closure. ECLIPSE has a dual-porosity option to model fractured waste forms and liner. Multi-phase flow and contaminant transport can also be simulated using time-dependent material properties.

CONCLUSION

We predicted the performance of three grouted waste disposal concepts in the unsaturated zone. Because the unsaturated zone performance relies almost entirely on the properties of the waste form, liner and closure cap, these predictions are generic. Based on our analysis, we need a closure to reduce water infiltration. We also need a liner to control the initial diffusion flux.

For site-specific applications, we need to conduct a PA factoring in 1) inventory, 2) alternative liners such as polymer and geotextile membranes, 3) degradation histories of waste forms, liners and closure, 4) hydrogeological conditions, and 5) cost. Rigorous groundwater modeling not only demonstrates compliance, but also assists the design and implementation of the waste disposal facility.

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