ASSESSING THE PERFORMANCE OF THE SALTSTONE WASTEFORM AT THE SAVANNAH RIVER SITE

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ABSTRACT

The radiological performance of the saltstone disposal facility (SDF) for low-level waste (LLW) at the Savannah River Site is being assessed in accordance with a U. S. Department of Energy Order which was issued in 1988. Saltstone is a high-nitrate concrete matrix formed as a result of solidification of LLW streams. Potential human exposures to radionuclides that will be disposed of in the facility are being addressed. Engineered features of the SDF reduce and retard releases of radionuclides from the facility, but degradation of the features must be considered. Because prediction of the extent and timing of degradation becomes more uncertain over time, predicted releases also become more uncertain, particularly for long-lived radionuclides still present in the facility far into the future. Preliminary analyses indicate that long-lived radionuclides are the saltstone constituents of greatest concern for radiological protection of groundwater resources. Application of federal drinking water standards to untreated groundwater may be a limiting requirement for LLW disposal facilities like the SDF, where the groundwater pathway is the most important for human exposure to radionuclides. The 4-mrem annual dose limit imposed by these standards is well below limits imposed by other regulations with which the disposal facilities must comply.

INTRODUCTION

A radiological performance assessment, as mandated by the U. S. Department of Energy (DOE) Order 5820.2A (1), is being conducted in a joint effort by Oak Ridge National Laboratory, Idaho National Engineering Laboratory, and Westinghouse Savannah River Company for the Saltstone Disposal Facility (SDF) at the Savannah River Site (SRS). This facility, which is currently under construction, is intended for disposal of low-level radioactive waste (LLW) which originates from the In Tank Precipitation process and the Effluent Treatment Facility at SRS. The preliminary performance assessment is nearing completion and will soon be presented to a peer review panel established by the DOE Order, whose function is to ensure the consistency and quality of performance assessments prepared for DOE LLW disposal facilities.

The purpose of DOE radiological performance assessments is to demonstrate compliance with the following performance objectives stated in DOE Order 5820.2A:

1. Protect public health and safety in accordance with standards specified in applicable DOE Environment, Safety and Health Orders, [for example, DOE Order 5400.5 (2)].
2. Assure that external exposure to the waste and concentrations of radioactive material which may be released to surface water, groundwater, soil, plants, and animals results in an effective dose equivalent that does not exceed 25 mrem/yr to any member of the public. Releases to the atmosphere shall meet the requirements of 40 CFR 61, Subpart H (3). Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable (ALARA).
3. Assure that the committed effective dose equivalents received by individuals who inadvertently may intrude into the facility after the loss of active institutional control (100 years) will not exceed 100 mrem/yr for continuous exposure or 500 mrem for a single acute exposure.
4. Protect groundwater resources consistent with federal, state, and local requirements.

Demonstrating with reasonable assurance that these performance objectives will be met by a planned LLW disposal facility requires consideration of the following: 1) potential releases from the facility, 2) transport of released radionuclides through the surrounding environment, and 3) potential scenarios by which human exposure to released radionuclides or radionuclides remaining in the disposal facility might occur. The analyses must be site-specific and must consider both near-term exposures (i.e., within the first few hundred years) and exposures occurring over thousands of years if long-lived radionuclides are present in the waste.

The types of analyses described above are being conducted for the SDF and are outlined in this paper. The SDF assessment considers the performance of an engineered LLW disposal facility in a humid climate. Problematic issues affecting the validity of results of the performance assessment are discussed. The problem posed by long-lived radionuclides in such a facility is particularly emphasized.

FACILITY LOCATION AND DESIGN

The SRS is located about 35 km from Aiken, SC, covers about 780 sq km, and is bordered to the southwest by the Savannah River (Fig. 1). The SRS receives an average of 120 cm of precipitation per year, of which about 38 cm infiltrates into the subsurface (4).

The SRS lies on Atlantic Coastal Plain sediments which extend up to 370 m beneath the site. The SDF will be located at Z-Area, which is on a topographic high at the SRS and is surrounded on three sides by creeks located about 1.2 to 1.8 km from the facility (Fig. 2). These creeks are all well within

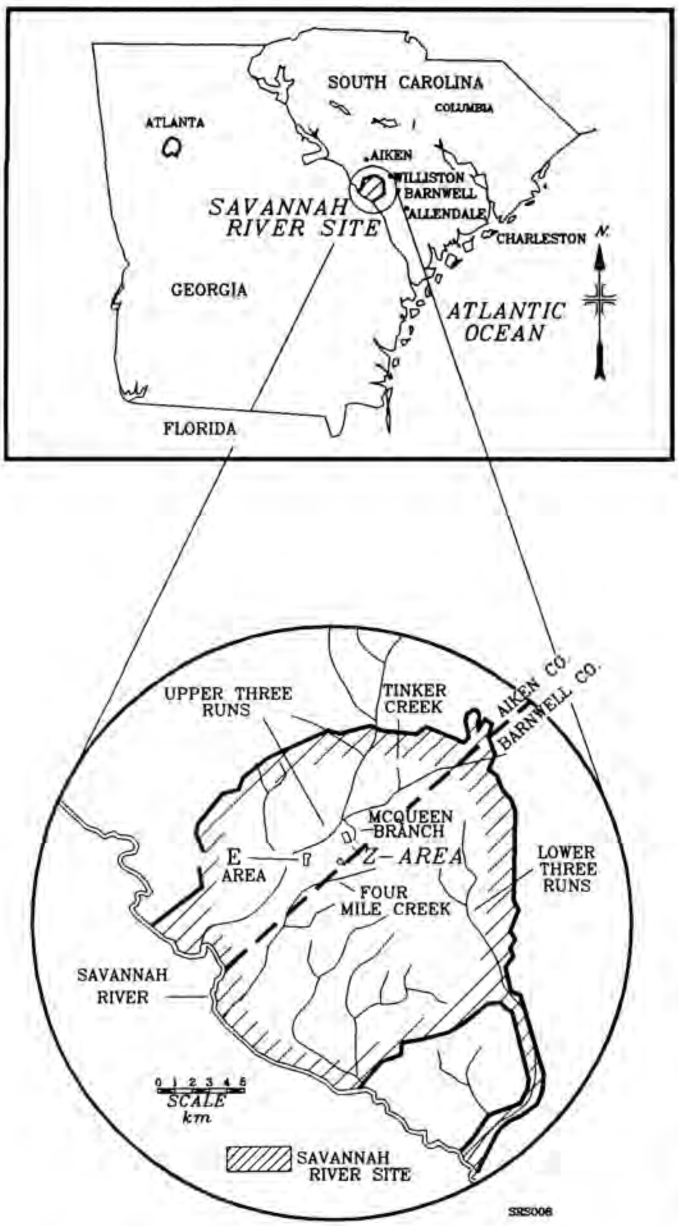

Fig. 1. Location map of the Savannah River Site.

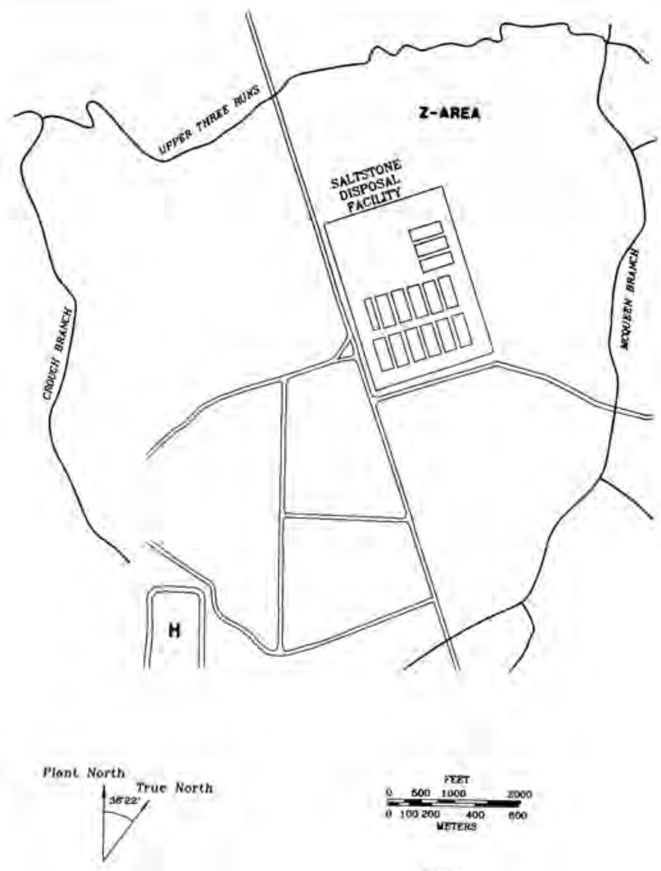

Fig. 2. Location map of Z-area with respect to nearby creeks.

the SRS boundary. The historic high water table lies at a minimum of 7 m below the existing grade. The underlying groundwater which is potentially subject to contamination from the SDF largely discharges to the three local creeks. Thus, off-site contamination of groundwater by the SDF is not likely. Discharge of contaminated groundwater to the creeks may result in contamination of surface water, but any such discharge will be diluted considerably by normal stream flows.

Wasteform and Containment System

The wasteform at the SDF is a concrete matrix referred to as saltstone, the components of which are a liquid LLW stream, Portland cement, fly ash, and blast furnace slag. The formulation of saltstone was designed to inhibit diffusion of the radionuclides from the matrix. In particular, the addition of slag is believed to chemically and physically alter the form of certain radionuclides in the matrix. The radionuclides of concern in the liquid waste include H-3, C-14, Cs-137/Ba-137m, Ru-106/Rh-106, Sr-90/Y-90, Tc-99, and I-129. Copious amounts of nitrate (approximately 7 wt%) are also present in the resulting wasteform. Other radionuclides and chemical compounds are present, but these are expected to be relatively unimportant in regard to potential human exposures.

The containment system for saltstone is composed of below-grade of concrete vaults, with 0.5-m-thick walls and 0.6-m-thick floors. The saltstone mixture described above will be poured as a slurry into 30 m x 30 m x 7.6 m cells. A total of 29 six-cell vaults are planned. Saltstone monoliths will be formed within the cells as the mixture cures. Shrinkage cracks have been observed to occur as saltstone cures. However, each cell will be poured in several layers to lessen the likelihood of continuous cracks through the final monolith, that could conduct water rapidly.

Closure System

Once a cell is filled and the monolith cured, a thin layer of uncontaminated grout will be poured to the level of the top of the cell. When all 6 cells in a vault are filled, permanent concrete roofs with a slope of 2% and average thickness of 0.5 m will be built over each vault. After approximately 30 years of operation, the SDF will be filled, and final closure will take place. Final closure will involve: 1) backfilling over and around all of the vaults to a depth of about 0.6 m over the vault roof, 2) placing a 0.75-m low-permeability soil layer over the backfill, 3) placing a 0.3-m gravel drainage layer over the low-permeability layer, 4) placing a geotextile fabric over the gravel layer to prevent clogging of the drainage layer by overlying soil, 5) placing 0.75 m of backfill over the geotextile fabric, and 6) placing a vegetative layer over the upper backfill layer for erosion control (Fig. 3). This layered earthen cap will be gently sloped, and riprap-lined drainage ditches will divert surface runoff.

RADIONUCLIDE RELEASES FROM THE FACILITY

There are many barriers to the release of radionuclides from the saltstone matrix to the geosphere. Contaminants must first migrate out of the matrix itself to the pore spaces, presumably via a diffusion-controlled process. Once in the pore spaces of the matrix, contaminants must be carried by infiltrating water through the concrete base of the vaults to the surrounding environment. However, the amount of infiltrating water is limited by the cover system.

If one ignored the possibility of failure of any of the engineered features of this facility, the challenge of determining radionuclide releases from the SDF would lie for the most part in predicting the release rate from and transport through the porous saltstone matrix with an acceptable degree of confidence. Volatile effluents are expected to be minimal.

Unfortunately, the performance of this facility must be predicted over much longer time periods than the minimum design life of the vaults, which is 30 years. Before final closure, maintenance of the vaults, consisting of filling cracks that develop, is planned. However, once the earthen cover is in place, old expansion cracks may reopen as the filling material deteriorates, settling cracks may occur, and other forms of concrete degradation may take place. In particular, corrosion of concrete reinforcement bars may lead to crumbling of the concrete vault over a long period of time. If the vault crumbles, the saltstone monolith would be exposed to the soil environment more directly. Weathering of a buried saltstone monolith may occur, but the geochemical mechanisms responsible for such weathering have not been identified with enough certainty to consider their effect quantitatively. Thus, there is considerable uncertainty in predicting the timing and extent of failures of engineered barriers.

Another important but difficult to predict phenomenon that affects the performance of the SDF is the gradual loss of integrity or function of earthen covers. Even with erosion controls in place, disruption of covers by roots, burrowing animals, or seismic events must be considered. Increased infiltration presumably will result from such disruptions, and the release of radionuclides from the facility may be affected.

TRANSPORT PATHWAYS AND EXPOSURE SCENARIOS

Transport of radionuclides released from the SDF to potential receptor locations depends on the mobility of contaminants in the vadose zone and saturated zones underlying the facility. Once in the saturated zone beneath the facility, the shortest time of travel to surface water for non-sorbing species is expected to be on the order of 40 years, based on our preliminary analysis of groundwater flow at the disposal site. Both groundwater and surface water provide media of transport and exposure for the radionuclides.

Contaminated groundwater or surface water could be used to irrigate crops and forage, leading to contamination of agricultural and dairy products. However, due to the abundance of precipitation, irrigation is not as widely practiced in the humid southeastern United States as it is in the arid west.

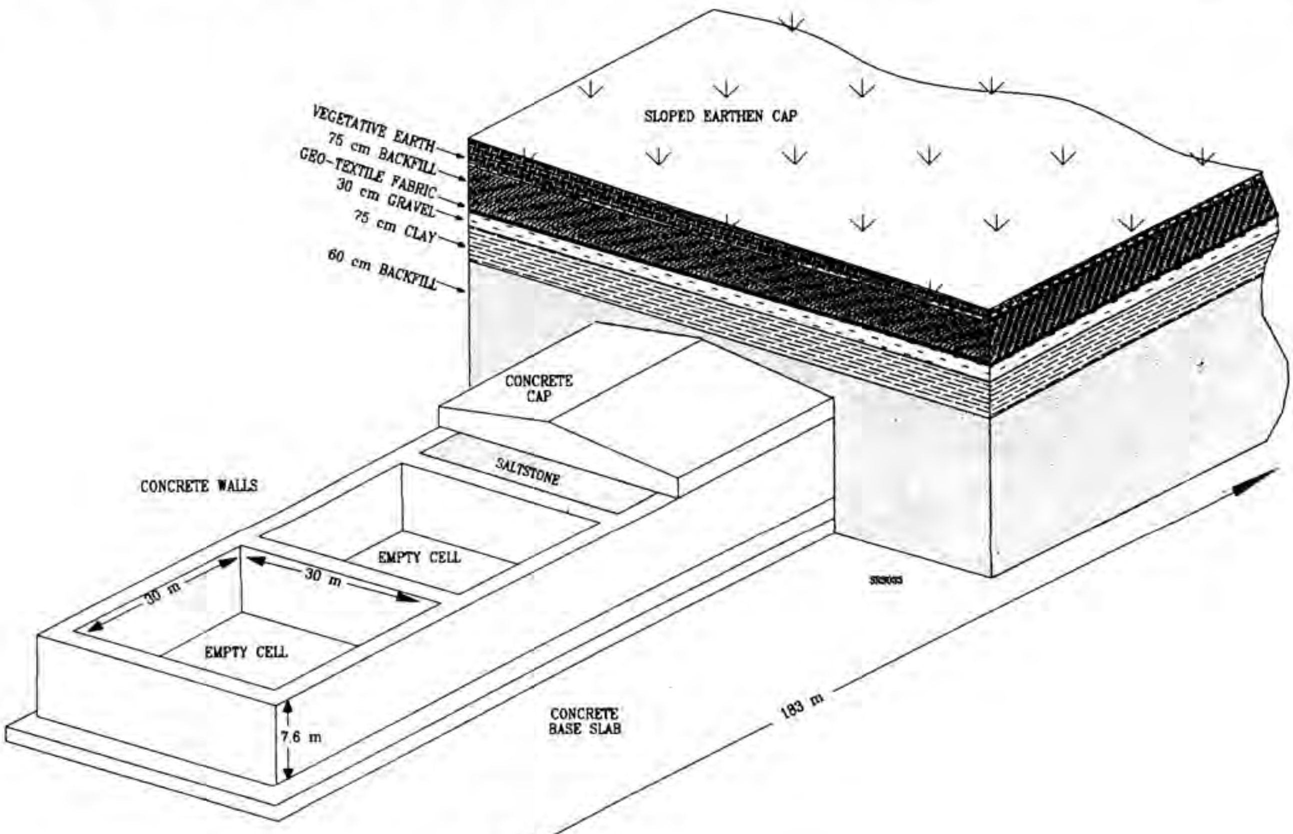

Fig. 3. Conceptual drawing of single saltstone vault.

Thus, the significance of irrigation pathways for human exposures, when compared with direct ingestion of contaminated water, is slight.

Potential receptors that are considered in a radiological performance assessment are of two types: the maximally exposed off-site individual and the inadvertent intruder. For LLW disposal facilities, it is assumed that institutional control over the site (i.e., the SRS) will be maintained for 100 years *after closure* of the facility, so that inadvertent intrusion into the facility is not possible during that period. Thus, only off-site individuals are potential receptors during institutional control, "off-site" during this time period referring to locations beyond the present boundary of the SRS. After active institutional control is abandoned, it is assumed that the disposal site is available for agriculture, construction development, or any other activities. In addition, after 100 years, off-site individuals are assumed to be located at distances as close as 100 m from the disposal facility.

Off-site individuals could be exposed to airborne effluents and contaminated food and water. Because atmospheric effluents are minimal from the SDF, contaminated groundwater and surface water are essentially the only environmental media of concern for off-site individuals. As noted previously, contaminated groundwater from the SDF would discharge to surface water near the disposal facility. Thus, during institutional control, only surface water discharges are important to off-site individuals at the boundary of the SRS. Exposure to contaminated groundwater may become important after 100 years, when the off-site individual is 100 m from the disposal facility.

Inadvertent intruders could conceivably excavate into the overburden for the purpose of constructing a building, or attempt to drill through the facility for the purpose of placing a well into one of the underlying aquifers. For an intact facility, contact with the reinforced concrete vault would discourage or prevent contact with the waste for either of these activities, and the wasteform is not likely to be blended with soil. External exposure to radionuclides is, therefore, the only reasonable mode of exposure of inadvertent intruders for an intact facility. The 0.5-m concrete roof and walls provide considerable shielding from external exposure in the event the overburden and backfill are removed by an intruder.

Degradation of engineered features, including the saltstone monolith itself, could affect the exposure scenarios that would be reasonable for an inadvertent intruder. If all materials crumbled essentially to powder, it is possible that radionuclides present could be mixed into soil used for planting of crops or that a well could be drilled through the facility to the underlying aquifer. It would be reasonable to presume that such crumbling will happen sometime far into the future, but it is not possible with the knowledge we have now to say when this might occur. Our analysis has indicated that vault or saltstone disintegration would not likely occur during the time that a significant fraction of the original inventory of long-lived radionuclides remains in the wasteform, since leaching by infiltrating water will diminish the slowly-decaying species over time. Thus, scenarios for direct intrusion into the saltstone were not considered to be important.

There is one other type of human receptor implicitly considered in the performance assessment process: an individual consuming 2 liters per day of groundwater 100 m downstream of the facility boundary. Consideration of this receptor arises out of the need to satisfy the fourth objective listed previously, i.e., to protect groundwater resources consistent with federal, state and local requirements. Federal drinking water standards for radionuclides (5) specify a limit on annual dose equivalent of 4 mrem to whole body or any organ from beta- and photon-emitters in the output (at the tap) of community water systems. To provide consistency with this standard, we assume that concentrations of all radionuclides in groundwater should be limited such that the annual effective dose equivalent from consumption of 2 liters per day of water from the source would not exceed 4 mrem. This requirement applies at 100 m from the disposal facility and at any time after disposal.

CRITICAL PATHWAYS/RADIONUCLIDES

The critical pathway leading to exposure to *radionuclides* disposed of in the SDF at locations beyond the disposal site boundary is the groundwater pathway. Other pathways for released radionuclides, including air and surface water, allow considerable mixing and dilution. External exposure is limited by the shielding afforded by the vaults, the earthen cover, and the saltstone itself.

For inadvertent intruders, external exposure is the only reasonable, and potentially important, exposure pathway. For a considerable period of time after disposal, intruders are protected from direct access to radionuclides in the SDF by the structural resistance of the facility to intrusive damage or destruction.

During institutional control over the SRS, off-site individuals are unlikely to receive significant exposure to effluents from the SDF due to negligible atmospheric releases and the dilution potential of surface water. After institutional control, however, individuals may be exposed to groundwater 100 m downgradient of the SDF. Consumption of groundwater at this location is the most important pathway for exposure of off-site individuals.

The critical radionuclides in the SDF are those that are present when degradation of the monolith and vaults, in the form of cracking, has progressed sufficiently that concentrations in the leachate approach allowable concentrations limits in groundwater as defined by drinking water standards. For the SDF, these constituents are expected to be the long-lived radionuclides Tc-99 and I-129. One potentially important aspect of the problem lies in the fact that little of the normally high infiltration of rainwater at the SRS passes underneath the vaults. This results in very little leachate volume but relatively high leachate concentrations in the unsaturated zone beneath the facility. Mixing of contaminated plumes with uncontaminated groundwater in the saturated zone is minimal. It has not been resolved whether the mixing that occurs when water is withdrawn from a well can be accounted for in evaluating compliance at the 100-m downgradient point.

PROBLEMATIC ISSUES

There are two major problematic issues that have arisen in the process of conducting a performance assessment for the SDF. One issue is the large amount of uncertainty associated with degradation of engineered features over long periods of time. The other is the overriding importance of Federal drinking water standards that are applied to groundwater in the vicinity of a LLW disposal facility.

There is a lack of information on longevity of concrete structures and earthen covers. While it is possible to consider the dynamics of degradation mechanisms, there is generally not sufficient site-specific information, especially for the very long time frames that must be considered in performance assessments. The timing of degradation processes may be most important for the long-lived radionuclides. Generally, shorter-lived radionuclides, such as H-3 and Ru-106/Rh-106, decay within the time period that confidence in structural integrity is high, and prediction of the leaching behavior may be more certain. Longer-lived radionuclides, although essentially constant in inventory over time, are gradually leached from the facility over a very long period of time during which confidence in the ability to predict structural integrity diminishes. If, for example, Tc-99 were leached from the facility at a rate such that an insignificant amount remained in the SDF after 1000 years, it would be essential to know if the facility would be intact over that period of time. In this case, significant failure at 500 years may give a very different result with respect to intruder doses than failure at 1500 years.

Federal drinking water standards were originally developed for application to community water systems that incorporate water treatment. Applying these standards directly to a groundwater resource should at least take into consideration the size of a well screen that would be necessary to withdraw a reasonable amount of water for consumption purposes. At Z-Area, this may be a 30-foot screen for the upper aquifer and a somewhat smaller screen for the lower aquifer. In fact, the location of Z-Area is such that development of a water supply downstream of the facility is extremely unlikely in the aquifer system of concern. Such considerations can significantly affect assessment results. However, the current application of these standards does not address the resource potential of an aquifer underlying a facility or the required screen size, and concomitant dilution, necessary to develop the aquifer as a water supply. The dose limit of 4 mrem per year for groundwater protection renders this requirement overriding in importance for facilities that are designed to protect the inadvertent intruder as adequately as the SDF; however, the compliance objective may not be based on reasonable assumptions.

CONCLUSIONS

The integrity of a LLW disposal facility over the period of time that radionuclides are present in significant amounts is an important aspect of engineered facilities such as the SDF. Ideally, engineered features are designed to delay natural processes such as leaching until radioactive decay reduces the inventory of radionuclides in the facility. This engineered delay provides a means of protecting off-site individuals from exposure to released radionuclides and inadvertent intruders from contact with the LLW. The engineered features of the SDF also offer considerable protection to inadvertent intruders from external exposure to radionuclides in the wasteform. Unfortunately, the long-term behavior of materials in the environment at the SRS is very uncertain. While mechanisms can be identified that might contribute to degradation, the timing and extent of failures are not very predictable, and uncertainties are very large.

The performance of the SDF relies most heavily on the ability of the engineered features, which include the wasteform itself, the concrete containment vaults, and the cover system, to protect groundwater resources underlying the facility in accordance with Federal drinking water standards. The application of these standards to untreated groundwater is without doubt the most confining regulation that applies to this facility.

REFERENCES

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