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ELEMENTS OF UNCERTAINTY IN A RADIOLOGICAL PERFORMANCE ASSESSMENT OF A SALTSTONE DISPOSAL FACILITY FOR LOW LEVEL WASTE

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ELEMENTS OF UNCERTAINTY IN A RADIOLOGICAL PERFORMANCE ASSESSMENT OF A SALTSTONE DISPOSAL FACILITY FOR LOW-LEVEL WASTE

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Abstract

Oak Ridge National Laboratory is currently conducting a radiological performance assessment for the Saltstone Disposal Facility at the Savannah River Site near Aiken, South Carolina. Saltstone is a solidified, low-level waste form which contains very low levels of radionuclides but considerable levels of nitrate. The preliminary results of the performance assessment indicate that the final outcome will be very sensitive to the degradation scenario for the cover and containment system for this facility. The uncertainty in the results beyond several hundred years, arising from the choice of elements in this scenario, is extremely large due to the limited knowledge of the behavior of the clay and cementitious materials beyond this time frame. Design of low-level waste facilities should address this uncertainty, and policy makers and regulators should decide both what the tolerable level of uncertainty is and the length of time over which a facility's performance should be predictively evaluated.

Introduction

The U. S. Department of Energy (DOE) Order 5820.2A (DOE 1988a) requires a site-specific radiological performance assessment for each DOE low-level waste (LLW) disposal facility designed and utilized subsequent to issuance of the order. The purpose of an assessment is to demonstrate compliance with performance objectives for DOE LLW management established in the order. These performance objectives are as follows:

1) Protect public health and safety in accordance with radiation protection standards specified in DOE Order 5400.3 (DOE 1988b) and other DOE Orders;

2) Ensure that external exposure to the waste and concentrations of radioactive material that may be released into 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 (EPA 1987). Reasonable effort shall be made to maintain release of radioactivity in effluents to the general environment as low as reasonably achievable (ALARA);

3) Ensure 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.

The performance assessment for each particular facility is intended to be a "living" document, in that it is to be maintained during the operational period of the facility and modified as warranted by new information.

Oak Ridge National Laboratory has been tasked with doing a radiological performance assessment of the LLW Saltstone Disposal Facility (SDF) at the Savannah River Site (SRS) in a joint effort with the Idaho National Engineering Laboratory and Hanford. The SDF handles disposal of liquid waste streams which are solidified in a cement matrix. A slurry consisting of a high nitrate-content salt solution, Portland cement, flyash, and slag is piped into below- grade concrete vaults. Upon solidification of the resulting monolith of saltstone, the remaining headspace will be filled with clean cement and the vaults will be protected from infiltration until final closure with various overburden layers.

The most challenging aspect of this, and perhaps all, performance assessments involves predicting the long-term performance of the various engineered features of the waste-form, containment, and closure design over the time period for which significant quantities of radionuclides are present in the facility. There is no specific regulatory guidance on the length of time for which potential exposure must be predicted nor on the amount of uncertainty which can be tolerated. The remainder of this paper will be devoted to elucidating the elements of this particular problem with respect to the ongoing SDF Performance Assessment. A description of the engineered features of the facility is provided below, along with the analytical approach being taken to address its long-term performance.

The SRS Saltstone Facility

The SRS was acquired by the U. S. government in 1950 and covers approximately 780 sq km (300 sq mi) in southwestern South Carolina. It is located about 35 km (22 mi) from Aiken, SC, and is bordered to the southwest by the Savannah River (Figure 1), which also borders northeastern Georgia. As is the case with other sites in the DOE complex, waste management and environmental restoration have come to the forefront of activities at SRS in the last decade.

The SRS lies on Atlantic Coastal Plain sediments, which extend up to 370 m (1,200 ft) beneath the site. Coastal Plain sediments are underlain by Triassic sediments in some areas and by weathered bedrock in others. Under the SDF site, in Z-Area (Figure 1), the Triassic sediments are absent. The Z-Area is on a topographic high, surrounded on three sides by creeks which are about 1.2 to 1.8 km (0.7 to 1.1 mi) from the facility (Figure 2). The historic high water table lies at a minimum of 7 m (25 ft) below the existing grade. The groundwater under the SDF largely discharges to three local creeks. A lower aquifer, occurring predominantly in the Middendorf formation, does not discharge to the local creeks but rather passes underneath, discharging to the Savannah River. This lower aquifer is unaffected by any downward migration of contaminants due to its lack of hydraulic connection to overlying aquifers at Z-Area. The hydrology of Z-Area is such, then, that off-site contamination as a result of groundwater contamination from a waste disposal facility is unlikely to be significant. Discharge of contaminated groundwater to surface water may occur, but dilution in streams provides a large amount of protection to potential water users.

The design of the individual vaults into which the saltstone slurry will be poured is illustrated in Figure 3. A total of 29 six-cell vaults will be filled over the next 30 years, covering an area of about 2.5 sq km (1 sq mi). When all vaults are full, an earthen cover will be placed over the entire facility (Figure 4) to contain elements similar to those shown in Figure 3. As new information is gathered on the effectiveness of certain cover designs, modifications to the present cover design may be made before actual emplacement.

There are many barriers to the release of radionuclides from the saltstone matrix to the geosphere. The elements must first migrate out of the matrix itself to the pore spaces via a diffusion-controlled process. The formulation of saltstone was designed to inhibit diffusion of the radionuclides, particularly Tc-99, from the matrix by the addition of slag, which is believed to chemically and physically alter the form of certain nuclides. Once in the pore spaces of the matrix, the elements must be carried by infiltrating water through the 0.6 m (24 in) thick concrete base of the vaults to the surrounding environment. Infiltrating water, however, is limited by the cover system, which includes a very low hydraulic conductivity clay layer and an overlying drainage layer to remove excluded water.

As stated in DOE Order 5820.2A, the SDF must be designed to meet federal, state and local requirements for the protection of groundwater, as well as satisfy the other requirements outlined previously. The U. S. Environmental Protection Agency's (EPA's) drinking water standard, which is being applied to groundwater for the purpose of evaluating compliance, limits the annual dose received as a result of groundwater contaminated by radionuclides to 4 mrem (EPA 1990). This standard also specifies maximum contaminant levels for various chemical compounds that are believed to pose a health risk, which also must be considered at the SDF. This drinking water standard is the most stringent standard that applies to facilities like the SDF at SRS because of the negligible potential for exposure to waste elements through pathways other than groundwater.

The radionuclides of consequence in the liquid waste to be solidified in a saltstone matrix include H-3, Cs-137/Ba-137m, Ru-106/Rh-106, Sr-90/Y-90, Tc-99 and I-129. Other radionuclides are present but in very small quantities and are thus relatively unimportant. The salt solution which is used to produce saltstone contains less radioactivity than the Nuclear Regulatory Commission's (NRC's) Class A limits (NRC 1986).

Nitrate is present in the saltstone at very high concentrations (about 7 wt%) and thus is of potential concern from the standpoint of EPA's drinking water standard of 10 mg/L for NO_3^- as N. Nitrate may indeed be the limiting contaminant of concern for the SDF. Significant amounts of chromium are also present in the saltstone, but it has been exempted from classification as a hazardous waste based on results from EPA's Extraction Procedure (EP) and Toxicity Characterization Leaching Procedure (TCLP) test procedures (Langton 1988). Chromium is not expected to exceed EPA drinking water standards because of its relatively low leachability.

Analysis

Demonstration of compliance with DOE Order 5820.2A requires that pathways to potential receptors be identified and potential exposures be predicted over an indefinite period of time. This must be done for three recognized time periods of concern: the operational time period, during which waste is being placed in the facility; the post-closure institutional control time period, during which the entire SRS site is still being patrolled and site boundaries are still maintained; and the post-institutional control time period, during which the site and facility may be intruded upon. The operational time period is expected to be on the order of thirty years, while the post-closure institutional control period is expected to extend control over the facility an additional 100 years.

Potential receptors fall into two categories: on-site receptors, referred to as inadvertent intruders, and off-site receptors. During institutional control, on-site receptors are not present, since the performance assessment does not cover occupational exposure which is addressed in required safety analysis reports for LLW facilities. Thus, for the first 130 years of the facility's existence, the only potential exposures considered are for off-site individuals. After 130 years, the possibility of excavation or drilling into the facility by inadvertent intruders must be considered.

An intact, or non-degraded, SDF is fairly robust from the standpoint of on-site receptors. The massive concrete buffer (almost 0.5-m-thick walls and ceiling) around the saltstone monolith makes damage due to well drilling or excavation highly unlikely. Direct external exposure to an intruder is the only credible means of exposure other than ingestion of groundwater but is minimal as a result of this concrete barrier. Groundwater is sufficiently protected while the SDF is intact, according to preliminary analyses which consider the minimal infiltration afforded by the cover system and the low leachability of the saltstone matrix. Thus, off-site receptors may also be protected during the time period the facility can be assumed to be fully intact.

Over long periods of time, however, it is expected that natural processes may degrade the cover and containment systems so that infiltration into the facility is increased and the ability of the monolith to withstand leaching is compromised. Erosion of ground surfaces, intrusion by burrowing animals or plant roots, and seismic events are potential sources of disruption to infiltration barriers. Cracks in the concrete vaults and the saltstone monolith that exist after construction or that develop as a result of settling may increase leaching to an unacceptable degree. Spalling of the concrete vaults may eventually lead to crumbling of the shell around the monoliths far into the future.

Because many of the radionuclides in the SDF are relatively short-lived, it is expected that they will have decayed to insignificant levels by the time natural processes have compromised the containment of the facility to any significant degree. Iodine-129, Tc-99 and nitrate are, therefore, the elements of concern in this facility. The half-lives of the Tc-99 and I-129 are extremely long (210,000 and 15 million years respectively), and, thus, radioactive decay is not an issue from the standpoint of reduction in the source term over the time period of the performance assessment. Leaching of the radionuclides and nitrates will reduce the source term over time, however. The assumptions made in devising a scenario describing the time sequence of degradation may therefore be crucial to the outcome of the performance assessment.

Much of the uncertainty in the results of individual exposure analyses as a consequence of LLW disposal lies not in the wide range in values of quantifiable parameters, but in the wide range in credible scenarios describing conditions at the facility hundreds and thousands of years into the future. It is virtually impossible to quantify the probability of a given degree of degradation at any particular time due to the fact that many of the processes are not well understood, especially over periods of time considered in performance assessments. Since there is not an official time cutoff for calculating exposures for DOE radiological performance assessments and since uncertainties become unfathomable after the first several hundred years, the manner in which performance assessment results can be used in decision-making is poorly defined.

Conclusions

Solidification of LLW in a cement matrix, as is being done at the SDF, appears to be an excellent long-term solution to the problem of subsidence in waste disposal facilities, and a means of radically reducing the leachability of wastes. However, because long-lived radionuclides and non-decaying substances of concern may outlast the lifetime of engineered containment, these potential contaminants may adversely impact the performance of a facility at some time in the future.

Degradation of engineered systems, therefore, must be addressed in performance assessments. Technical justification for degradation of the clay and cementitious materials making up the engineered cover and containment systems becomes moot, however, beyond several hundred years. Recognizing that there is considerable uncertainty arising from the limited knowledge of degradation mechanisms and timing, there must be a concerted effort by both technical individuals involved in designing LLW facilities and policy makers and regulators to address this large uncertainty. Design of facilities should acknowledge the inevitability of degradation of protective and containment features. Policy makers and regulators must address the issue of the amount of uncertainty that will be tolerated in performance evaluations and the length of time that should be considered in assessing performance.

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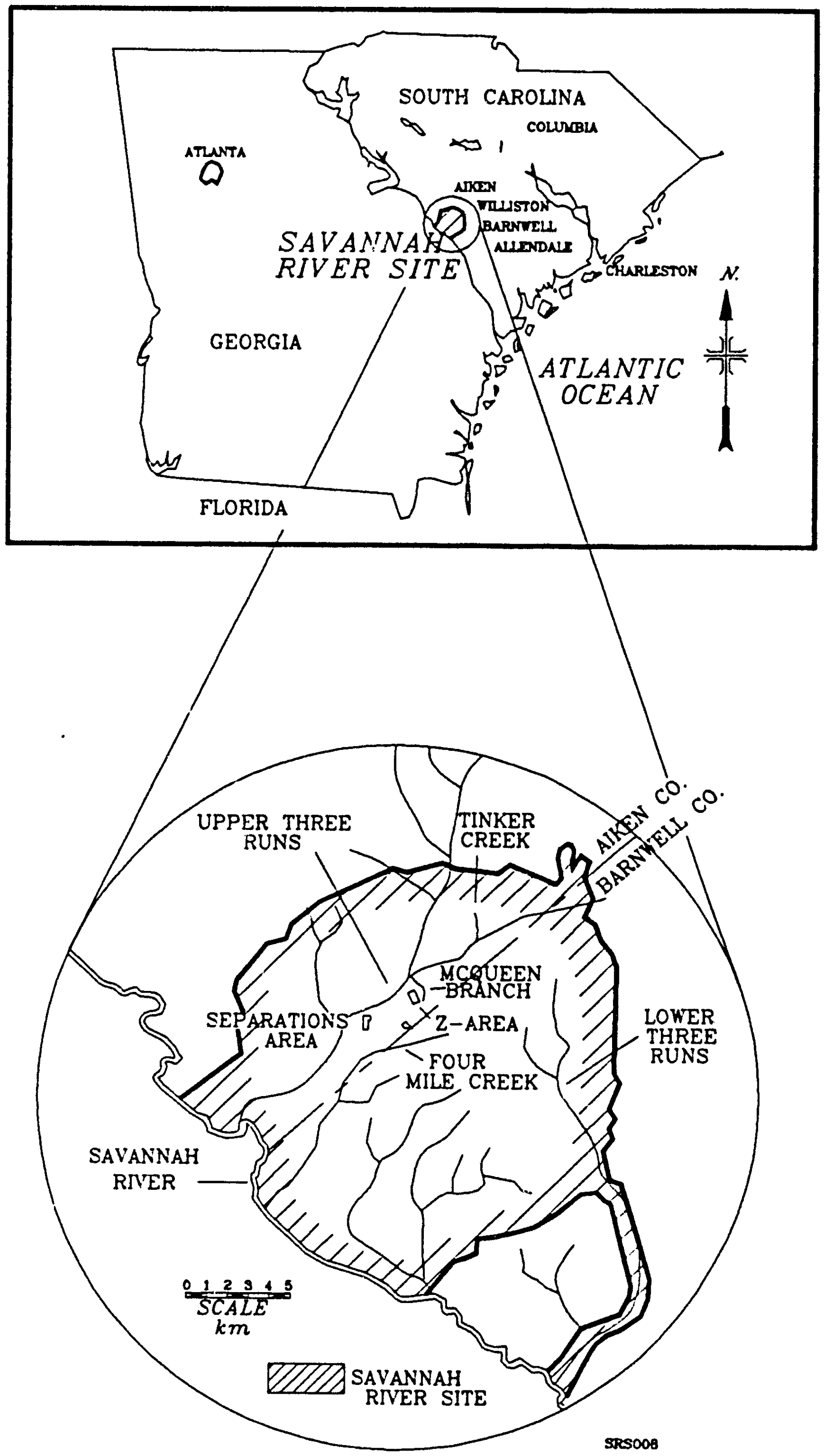

Fig. 1. Location map of the Savannah River Site.

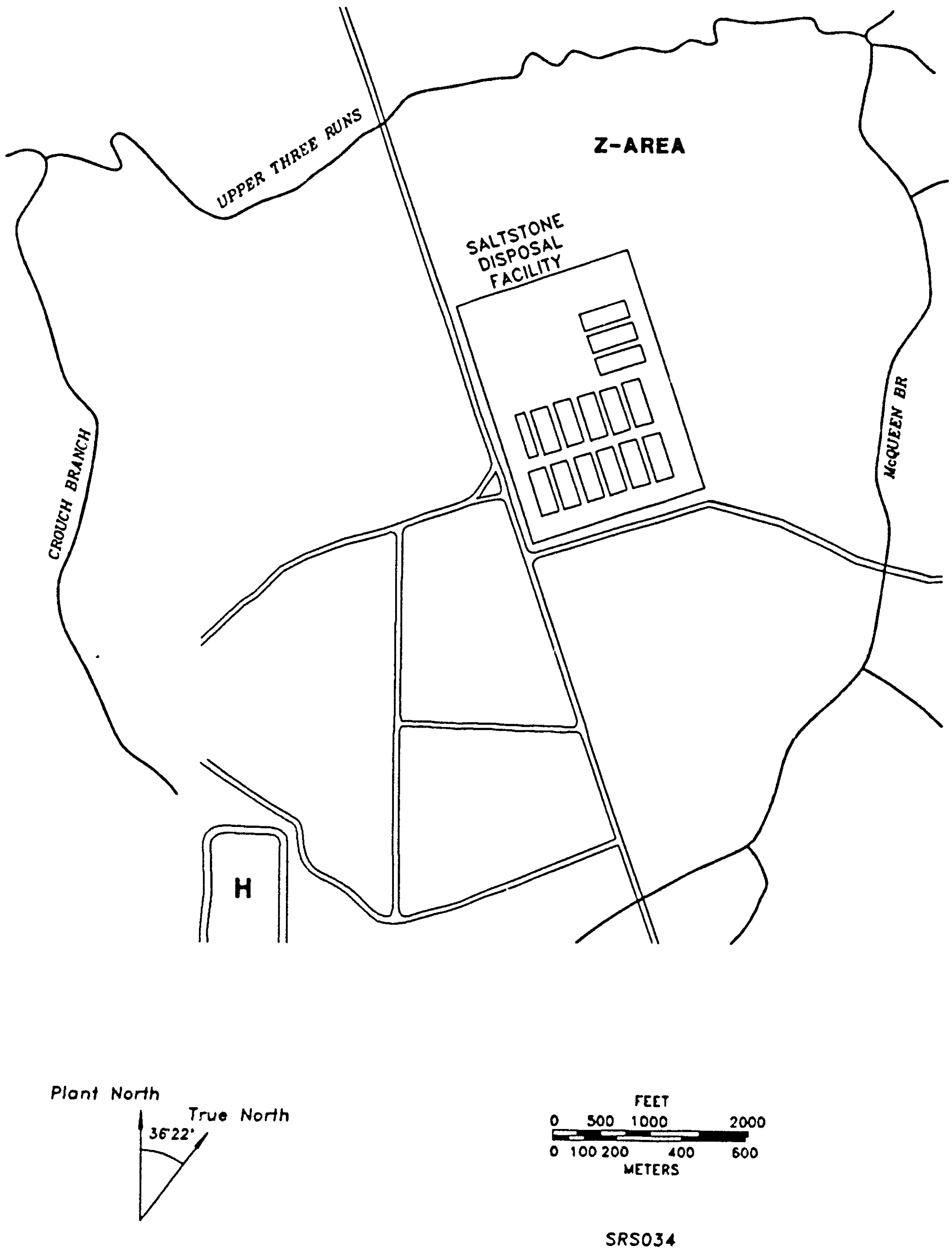

Fig. 2. Location map of Z-Area with respect to nearby creeks.

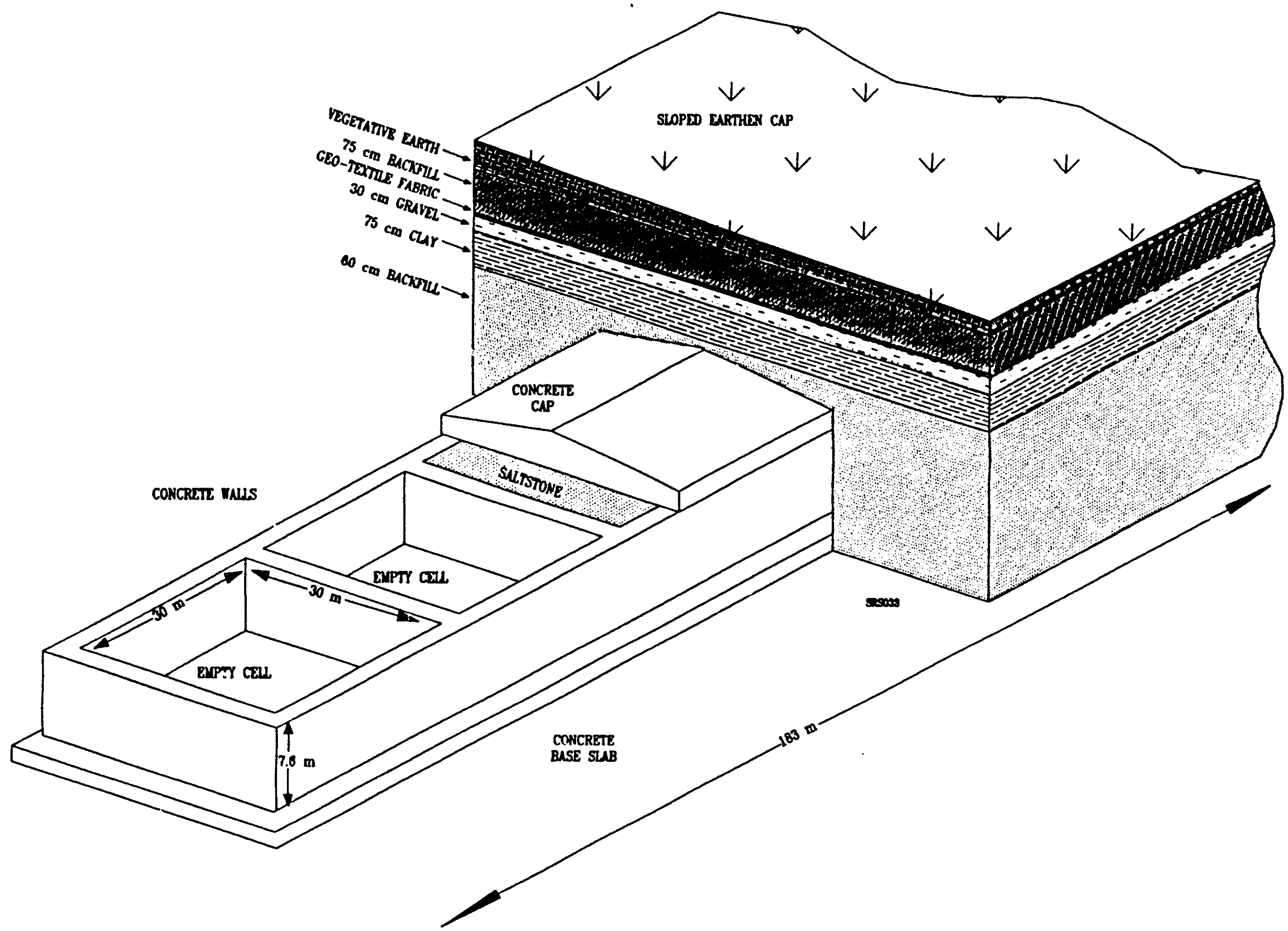

Fig. 3. Conceptual drawing of single saltstone vault, showing major features.

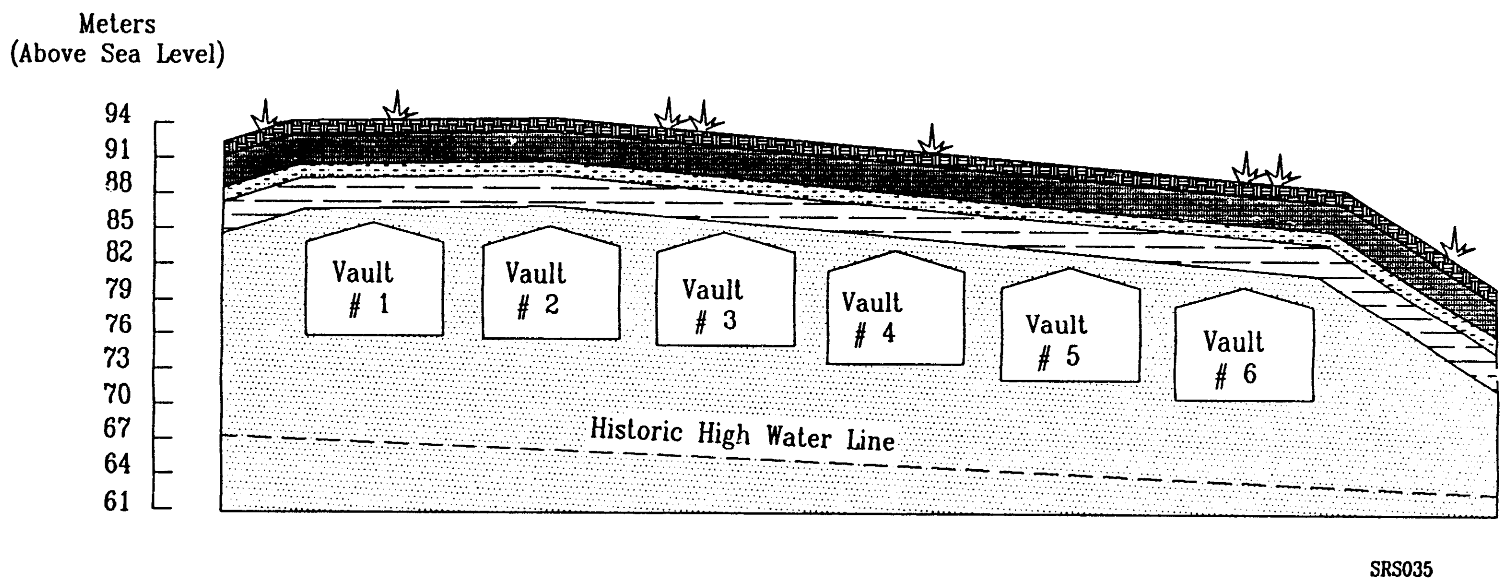

Fig. 4. Cross-sectional drawing of Saltstone Disposal Facility at Z-Area, showing cover and water table.

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