EVALUATION OF ENGINEERED BARRIERS AT THE IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY

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ABSTRACT

The Subsurface Disposal (SDA) of the Radioactive Waste Management Complex (RWMC) serves as the low-level waste burial ground at the Idaho National Engineering and Environmental Laboratory (INEEL). The low-level wastes are buried in trenches, pits, and soil vaults in surficial sediments. A closure/post-closure plan must be written prior to closure of the SDA. The closure plan for the facility must include a design for an engineered barrier closure cover that will meet all applicable regulatory requirements. This paper describes the approach being followed at the INEEL to choose an appropriate cover design for the SDA closure.

Regulatory requirements and performance objectives potentially applicable to closure of the SDA were identified. Technical issues related to SDA closure were identified from a literature search of previous arid site engineered barrier studies and from previous SDA closure cover evaluations. Five engineered barrier conceptual design alternatives were identified: (1) a bio/capillary barrier cover, (2) a thin soil cover, (3) a thick soil cover, (4) a Resource Conservation and Recovery Act (RCRA) cover, and (5) a concrete sealed surface cover. Two of these designs (the bio/capillary barrier cover and the thick soil cover) were chosen for in situ hydraulic testing, rather than all five, in order to maximize the amount of information generated relative to projected project costs. Testing of these two cover designs provides data to quantify hydrologic model input parameters and for verification of site-specific hydrologic models for long-term closure cover performance evaluation and detailed analysis of closure cover alternatives.

The specific objectives of the field tests are to determine the water balance for the two covers over several years and to determine cover soil physical and hydraulic properties. Both of the cover designs were constructed in May 1996 at the Engineered Barriers Test Facility (EBTF) located adjacent to the SDA.

The EBTF consists of 3 x 3 x 3 m concrete-enclosed test plots which are monitored through a main access trench and adjacent instrument control room. The facility provides ten test plots, five on each side of the access trench. The plots are instrumented in three dimensions at a high density using an array of available automated sensors. The facility provides a total of almost 900 simultaneous data points, which require virtually unattended operation. The computer-automated data retrieval and storage system also allows remote user access and download of real-time data collected at the EBTF. The EBTF instrument platform allows measurement of critical performance parameters including infiltration rate, moisture content, matric potential, drainage rate and volume, and temperature over the full range of expected values. Monitoring ports installed in each plot provide access for soil pore water sample collection and direct ion sampling within the barrier profile. Test plots for each cover design were replicated four times with each cover design being tested under two treatments: (1) natural meteorologic conditions and (2) supplemental precipitation conditions. Two additional test plots were constructed for in situ hydraulic property testing and for destructive sampling to provide soil samples for laboratory determination of hydraulic and physical properties of the cover soil.
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Barrier testing currently being conducted at the EBTF includes monitoring barrier performance during and after extreme wetting conditions as well as in situ hydraulic property testing. Barrier performance is also measured under the conditions of normal precipitation and performance will be measured under automated artificially induced precipitation at two times normal precipitation.

INTRODUCTION

The Subsurface Disposal Area (SDA) of the Radioactive Waste Management Complex (RWMC) is one of several waste management facilities at the Idaho National Engineering and Environmental Laboratory (INEEL), but it is the INEEL's only operating low-level waste disposal area. Wastes have been buried under 1 to 2 m of soil in trenches, pits and soil vaults excavated in surficial sediments. Department of Energy (DOE) Order 5820.2A, "Radioactive Waste Management" (DOE 1988) requires that a site specific, comprehensive closure plan be developed for each low-level waste facility. The closure plan is to be supported by a radiological performance assessment of the facility. The radiological performance assessment is a tool used to predict the potential environmental consequences of the low-level waste disposal facility. The performance assessment is based, in part, on long-term numerical simulations of water flow and radionuclide transport in the subsurface of the SDA. Current performance assessments of the SDA assume the presence of a closure cover that is effective in reducing net infiltration from 7 to 1 cm/yr. However, site-specific, field-validated data confirming the cover performance do not exist. The need for such data is evident in view of the potentially significant impacts of the cover on facility performance. This paper outlines the approach followed at the INEEL to choose an appropriate design for the SDA closure cover.

PERFORMANCE OBJECTIVES AND DESIGN GUIDANCE

The initial task in choosing a closure cover design for the low-level waste facility at the SDA involved identifying the appropriate regulatory requirements and performance objectives.1 The SDA low-level waste disposal site is subject to the authority of DOE orders, which offer low-level waste disposal site performance objectives. These objectives are defined in DOE Order 5820.2A, Chapter III, "Management of Low-Level Waste", and in DOE Order 5400.5, "Radiation Protection of the Public and the Environment." Although governed by DOE orders, performance objectives from both the Environmental Protection Agency (EPA) and Nuclear Regulatory Commission (NRC) were also considered to address topics not covered in detail by DOE. EPA performance objectives concerning radionuclide exposure were found in: 40 CFR 61, "National Emission Standards for Hazardous Air Pollutants" (Clean Air Act); 40 CFR 141, "National Interim Primary Drinking Water Regulations" (Safe Drinking Water Act); and 40 CFR 193 (proposed), "Environmental Standards for the Management, Storage, and Land Disposal of Low-Level Radioactive Waste and Naturally Occurring and Accelerator-Produced Waste." NRC performance objectives considered were found in 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste."

DOE closure cover design guidance is limited to the performance objectives found in the documents referred to above. Both EPA and NRC provide more detailed design guidance. Although not binding on DOE, the EPA and NRC guidance documents were consulted as valuable resources. EPA's guidance is the more detailed of the two, however, it is directed toward hazardous waste landfill closures.24 The EPA's recommended final cover ("RCRA cap") design incorporates three layers: (1) a top layer, (2) a middle drainage layer, and (3) an underlying low permeability layer. Gas venting layers and biobarriers may also be incorporated in the design under certain circumstances. This cover is intended for hazardous waste landfills constructed using EPA design guidance. These landfills include a low permeability layer of
compacted clay and a flexible membrane liner under the waste zone. However, any design that meets or exceeds the performance of the recommended design may be proposed.

The EPA and NRC have issued a much less detailed joint guidance for closure of low-level waste and mixed waste land disposal facilities. Differences between NRC-EPA and EPA guidance include:

- An additional drainage layer between the bottom soil component of the low permeability layer and the backfill covering the waste.
- An additional compacted clay layer immediately above the waste, if the solidified waste zone does not consist of an engineered vault structure with a top roof.

NRC guidance for closure of low-level waste disposal facilities is also contained in 10 CFR 61.62, "Land Disposal Facility Operation and Disposal Site Closure." Among other requirements, this document specifies that class C wastes must be disposed of such that "the top of the waste is a minimum of five meters below the top surface of the cover or must be disposed of with intruder barriers that are designed to protect against inadvertent intrusion for at least 500 years."

TECHNICAL ISSUES

The next step in the process of choosing an appropriate closure cover design consisted of identifying and analyzing technical issues related to SDA closure. This involved a literature search of previous arid site closure studies, including previous SDA closure cover evaluations. Technical issues analyzed included: water balance, radiological performance assessment, erosion, SDA soil engineering properties, sustaining vegetative top cover, effectiveness of alternative surface covers, effectiveness of geotextiles, biointrusion, gas generation, subsidence, freeze-thaw damage, seismic activity, design life, run-on/run-off control, and definition of future use scenarios. Analysis of the technical issues identified three basic cover designs that could potentially meet the performance objectives. These were:

1. Evapotranspiration (ET)- storage cover;
2. RCRA cover; and
3. Sealed surface cover

The ET-storage cover maximizes evapotranspiration and soil moisture storage using a thick soil cover with a vegetated surface. This cover has been widely used at arid climate Uranium Mill Tailings Remedial Action (UMTRA) and low-level waste sites.

The second design maximizes runoff and lateral drainage using the three-layer EPA (RCRA cover). This method has been used in climates ranging from arid to humid.

The sealed surface cover maximizes runoff by sealing the surface with an impermeable material, such as concrete and asphalt. This method has been used at humid climate sites including Maxey Flats, Savannah River, and others. This approach is not widely used at arid sites.

CLOSURE COVER CONCEPTUAL DESIGN ALTERNATIVES

After technical issue consideration, an adaptation of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process for identification and screening of remedial
alternatives was used to formulate preliminary closure cover conceptual design alternatives. The CERCLA process identifies general response actions; identifies and screens a range of technology types representative of each general response action; and combines favored technology types into alternatives which are subjected to more detailed analysis. Based on the information gathered to this point, five SDA closure cover design alternatives representing the three basic cover types were identified as potentially applicable for SDA closure. The alternatives included:

1. an ET-storage cover with a bio/capillary barrier (Fig. 1, Design 1);
2. a thin soil-only ET-storage cover (Fig. 1, Design 2);
3. a thick soil-only ET-storage cover (Fig. 1, Design 3);
4. a RCRA 3-layer cover (Fig. 1, Design 4); and
5. a concrete sealed surface cover (not shown; 0.5 m sulfur-polymer concrete over 1.0 m backfill)

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CLOSURE COVER DESIGN DATA NEEDS

Conformance of cover designs to performance objectives is determined by hydrologic modeling and radiological performance assessment. Field testing of closure covers will quantify hydrologic model input parameters and provide site-specific data required to calibrate and validate the model(s). Two numerical codes, UNSAT-H\textsuperscript{13} and Hydrologic Evaluation of Landfill Performance (HELP),\textsuperscript{14} were applied during the preliminary engineered-barrier evaluation. These models are likely to be used again as part of the performance assessment process. Therefore, the specific needs of these codes (UNSAT-H and HELP) must be met by the data collection.

Two of the five conceptual designs were proposed for field-testing:

- a design incorporating a bio/capillary barrier (Design 1, Fig. 1) and
- a single-layer thick soil-only design (Design 3, Fig. 1)

These two designs were selected for testing, rather than all five, in order to maximize the amount of information generated per testing dollar spent. Testing Design 3 will produce information on moisture migration through the entire 5 m soil profile, and will, therefore, also determine infiltration through Design 2 (thin soil). Testing of a RCRA cover was not recommended nor required, because the effectiveness of the RCRA cover is dependent on the integrity of the low-permeability layer and flexible membrane liner. The hydrologic performance of this design can be effectively modeled using experimentally determined input parameters and site-specific hydrologic models. Field testing of concrete barriers was not recommended due to the very high cost of closure of large areas (the SDA covers 38.8 hectares) using concrete.

The main objective of the proposed study is to determine the water balance of the two engineered-barrier designs.\textsuperscript{15} This will be accomplished by determining the water-balance components: evapotranspiration (ET), drainage, precipitation, run-on, run-off, and changes in water storage within the cover profile. The water-balance data will be used to evaluate the performance of the engineered barriers and to calibrate and validate both the UNSAT-H and HELP models. Additional site-specific hydrologic data are necessary to support the hydrologic modeling and to evaluate the performance of the engineered barriers. Moisture content and matric potential profiles, over time, are needed for validation of the UNSAT-H model. Saturated and unsaturated hydraulic conductivity, soil moisture characteristic curves, and effective porosity of the cover materials are needed as input parameters for the UNSAT-H code. Saturated hydraulic
conductivity, effective porosity, and effective depth of ET are used as input parameters for the HELP code. The effective depth of ET was identified as a sensitive input parameter for the HELP numerical code for simulating drainage from the test plots. Bulk density and particle density measurements are needed to calculate effective porosity. Results of particle-size analyses are an integral part of soil characterization in the test plots and will permit future comparison with soils used in the proposed SDA cover. Temperature profiles will be used to determine temperature effects from the engineered barriers test facility access trench and to aid in estimating water vapor transport. The performance of the bio/capillary barrier will be evaluated to determine its effectiveness in preventing both plant intrusion and water infiltration into the waste.

Data for the hydrologic modeling and performance assessment will be generated by (a) long-term monitoring of the two engineered-barrier designs under natural conditions, (b) long-term monitoring of the two cover designs under conditions of supplemental (applied) precipitation, (c) hydraulic and physical soil properties testing of the cover soil, and (d) post-test investigations. Long-term monitoring of the field plots will be performed under natural conditions for 3 to 7 or more years. However, the range of conditions evaluated by long-term monitoring is limited by meteorological factors and moisture storage characteristics of the soil in the field test plots. For example, the full wetness range needed to determine the functional relationship of moisture content to matric potential might not be experienced under natural conditions. Additionally, some of the soil properties of interest (e.g. particle-size analysis) cannot be determined using field techniques. Therefore, hydraulic and physical property testing will be used to evaluate parameters that are difficult or impossible to determine under natural, in situ conditions.

Supplemental precipitation will also be used to evaluate the performance of the two engineered-barrier designs under more severe (wetter) conditions than normally experienced at the SDA. The natural precipitation experienced for the 3 to 7 or more years of long-term monitoring will not provide the full range of conditions (i.e. 25-year flood, 100-year flood, melt of 100-year maximum snowpack, etc.) that might be experienced after actual RWMC closure. Hydrologic conditions under supplemental precipitation will yield valuable field data to calibrate and demonstrate validation of numerical models.

Post-test investigations will be performed after long-term monitoring and testing are complete. Changes in soil hydraulic and physical properties and in physical condition of the cover may occur during the 3 to 7 or more years of monitoring. The long-term monitoring and supplemental precipitation plots will be destructively sampled to characterize the physical condition of the cover (compaction, condition of geotextile liners, etc.) and to evaluate changes in soil hydraulic and physical properties.

ENGINEERED BARRIERS TEST FACILITY

A test facility was constructed adjacent to the SDA for the purpose of field testing the two cover designs (Fig. 2). The soil was excavated down to bedrock in order to build the plots. Since surface soil at this location is less than 3 m (10 ft) deep, soil was backfilled around the plots to the level of soil inside the plots. Sidewalls for each plot extend about 15 cm (6 in) above soil level to prevent run-on and run-off from the plots. An enclosed trench was constructed adjacent to the plots to provide access to certain instruments used in the plots and as a data collection center for automated instrumentation used in the test plots. The general layout of the engineered barriers test facility is shown in Fig. 3.

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Place Fig. 3 here.
Four test plots were constructed at the test facility for each of the two engineered barrier designs chosen for field evaluation. Two test plots of each design (replicates) will be subjected to natural meteorological conditions. The remaining two test plots of each design (replicates) will be subjected to supplemental precipitation conditions. Individual plot dimensions for these eight plots is $3 \times 3 \times 3$ m ($10 \times 10 \times 10$ ft). The depth of the test plots is shallower than the intended final cover due to test cost constraints. Nevertheless, the 3 m (10 ft) depth is sufficient to accommodate the bio/capillary barrier and overlying soil thickness unchanged from the original design and the anticipated rooting depth of the cover vegetation.

Two additional plots (with the same dimensions as above) were constructed at the test facility with the thick soil engineered-barrier design. One of these plots is being used for in situ hydraulic property testing of the cover soil. The other plot is subject to destructive sampling and will provide soil samples for laboratory determination of hydraulic and physical properties of the cover soil.

The instrumentation used for collecting the above data was chosen to (1) provide the appropriate site specific data, (2) be amenable to automatic data collection to provide timely measurements and reduce labor requirements, (3) provide some measure of variability within plots, and (4) provide redundancy in case of instrument failure. Instrumentation layouts for the cover design test plots are shown in Fig. 4.

**INITIAL OBSERVATIONS**

Test plot data collection commenced in July 1996. The plots have been monitored for approximately one year under ambient precipitation conditions with no vegetative cover to provide a baseline of data. Total moisture in the test plots decreased steadily from inception of monitoring to mid-November in 1996. Precipitation between then and early January 1997 brought total moisture back up to initial levels. In contrast to 1996, total test plot moisture increased steadily through the spring and summer of 1997. This is an illustration of the year-to-year variability that can occur at this site. During the winter of 1996-1997, infiltrating moisture penetrated to depths between 180 and 230 cm in the thick soil test plots but was effectively halted at the 160 cm depth by the capillary barrier in the bio/capillary barrier test plots.

**ACKNOWLEDGMENTS**

Work supported by the U.S. Department of Energy, Assistant Secretary for Environmental Management, under DOE Idaho Operations Office Contract DE-AC07-94ID13223.

**REFERENCES**


Fig. 1. SDA closure cover conceptual design alternatives.
Fig. 2. Location of the Subsurface Disposal Area (SDA) and the Engineered Barriers Test Facility at the INEEL.
Fig. 3. Plan (a) and side (b) views of the SDA Engineered Barriers Test Facility.
Fig. 4. Instrumentation layouts for the thick soil test plots [(a) top view; (b) side view] and the bio/capillary barrier test plots [(c) top view; (d) side view].
Report Number (14) INEEL/CON-97-00968

Publ. Date (11) 199802

Sponsor Code (18) DOE/EM XF

UC Category (19) UC-2000, DOE/ER

DOE