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# Engineering Design File

# Liner and Final Cover Long Term Performance Evaluation and Final Cover Life Cycle Expectation

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This study provides the basis for engineering analyses for designing the INEEL CERCLA Disposal Facility (ICDF) landfill liner and cover systems. For each design analysis, the associated applicable or relevant and appropriate requirements (ARARs) and performance design criteria are defined.

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# ABSTRACT

This study presents the engineering analyses for designing the INEEL CERCLA Disposal Facility landfill liner and cover systems. For each design analysis, the associated applicable or relevant and appropriate requirements and performance design criteria are defined, and the appropriate calculation completed. This study also includes an explanation of how the design analyses demonstrate compliance with the required liner and cover service life. In addition, an explanation is provided to demonstrate quantitatively that the ICDF landfill design will meet the required design life of 1,000 years.

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# ACRONYMS

| | |
|---|---|
| ALR | action leakage rate |
| ARAR | applicable or relevant and appropriate requirement |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| CFR | Code of Federal Regulations |
| EDF | engineering design file |
| EPA | Environmental Protection Agency |
| FS | factor of safety |
| GCL | geosynthetic clay liner |
| HDPE | high-density polyethylene |
| HI | hazard index |
| ICDF | INEEL CERCLA Disposal Facility |
| IDAPA | Idaho Administrative Procedures Act |
| INEEL | Idaho National Engineering and Environmental Laboratory |
| LCRS | leachate collection recovery system |
| MCL | maximum contaminant level |
| MUSLE | modified universal soil loss equation |
| NOAA | National Oceanic and Atmospheric Administration |
| NRC | Nuclear Regulatory Commission |
| PC | performance category |
| PCB | polychlorinated biphenyl |
| PLDRS | primary leak detection recovery system |
| PMP | probable maximum precipitation |
| RCRA | Resource Conservation and Recovery Act |
| SBL | soil bentonite liner |
| SLDRS | secondary leak detection recovery system |

| | |
|---|---|
| SPC | specification |
| SRPA | Snake River Plain Aquifer |
| SSSTF | Staging, Storage, Sizing, and Treatment Facility |
| WAC | Waste Acceptance Criteria |
| WAG | waste area group |

# Liner and Final Cover Long Term Performance Evaluation and Final Cover Life Cycle Expectation

## 1. INTRODUCTION

The INEEL CERCLA Disposal Facility (ICDF) Complex will consist of the Staging, Storage, Sizing, and Treatment Facility (SSSTF) and the landfill with its associated evaporation pond and leachate collection system. The landfill will enable the various waste area groups (WAGs) from the Idaho National Engineering and Environmental Laboratory (INEEL) to dispose of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) waste meeting the ICDF agency-approved Waste Acceptance Criteria (WAC). The landfill will accept only low-level radioactive and hazardous mixed waste for CERCLA-generated contaminated bulk soil, debris, and treated waste that are generated at the INEEL and meet the agency-approved WAC.

Operationally, waste arriving at the ICDF landfill will have already passed through the SSSTF for waste profile and WAC verification. The waste will arrive in various forms and sizes that will include, but not be limited to, soil, boxes, bags, drums, tanks, and piping. Landfill equipment will then spread and compact the waste material in accordance with accepted waste placement and operation. A "clean" working surface will always be maintained over the waste and shall be the area where the various trucks can back up to dispose of the waste. Leachate from the landfill will be collected and pumped to a lined surface impoundment for evaporation. Sediment will be removed periodically from the ponds and placed back into the landfill after processing through the SSSTF if necessary. These ponds will also accept other CERCLA-generated waste liquids from INEEL that meet the agency-approved evaporation pond WAC.

The ICDF landfill will be lined with a double composite liner system and include leachate collection and leak detection recovery systems. After the landfilled waste is placed to its final grades, it will be covered with a robust cover barrier system engineered to minimize infiltration for 1,000 years and conceivably years beyond. The evaporation ponds will also be lined with a double composite liner system and include a leak detection recovery system.

The landfill and evaporation pond liner and leachate collection systems are designed to exceed current regulatory barrier requirements for low-level radioactive and hazardous mixed waste. The evaporation ponds will remain operational through the active and post-closure life of the ICDF landfill or until leachate is no longer being accumulated. These systems will perform for the active life of the facility plus a 30-year post-closure period, at which time the landfill will be capped with an earthen barrier. During this time, the performance of these systems will be monitored and maintenance activities performed to mitigate problems that might be encountered. However, the ICDF landfill must isolate waste much longer than the 30-year post-closure period (i.e., beyond 2095). The geosynthetic geomembrane barrier in the landfill liner and cover systems cannot be relied on to perform satisfactorily for more than 1,000 years. Consequently, the cover must be designed to provide a long-term barrier to isolate the waste for a minimum of 1,000 years.

The objective of this study is to develop the basis for the design and assess the performance of the ICDF landfill and evaporation pond liner system and permanent isolation cover barrier for their respective life cycles. This study is divided into seven sections. Section 1 includes the purpose, regulatory, and performance requirements for the ICDF Complex. The landfill and evaporation pond liner design analysis is described in Section 2. Section 3 provides the design analysis for the permanent cover barrier. The expected long-term performance of the materials used in the liner and cover systems is provided in Section 4. Other long-term issues including human intrusion and potentially disruptive natural events are discussed in Section 5. The conclusion and references are provided in Sections 6 and 7, respectively. This document also references both the design studies performed under separate engineering design files (EDF) and calculations that are included in the appendices attached to this document. These appendices primarily address the liner and cover design components that were not included in the other design studies, and include the following:

- Appendix A: Stress Induced in Geomembrane and Geosynthetic Clay Liner
- Appendix B: Geotextile Puncture Resistance
- Appendix C: Geomembrane Wind Lift Analysis
- Appendix D: Anchor Trench Pullout Resistance Calculation
- Appendix E: Water Erosion of Final Cover Surface
- Appendix F: Side Slope Armor Design
- Appendix G: Bio-Intrusion Analysis
- Appendix H: Soil Filter Layer Analysis
- Appendix I: Freeze-Thaw Calculation
- Appendix J: Equipment Loads on Geosynthetics
- Appendix K: Analysis of Side Slope Riprap for the 500-year Flood Event.

## 1.1 Purpose

This study provides the basis for the design of the ICDF landfill and evaporation pond liner system and permanent cover barrier. The design basis consisted of specific design tasks that were identified for the liner in the ICDF landfill and evaporation ponds and permanent cover. The design tasks identified for the ICDF landfill and evaporation liner system are as follows:

- Soil bentonite liner (SBL) design
- Compatibility analysis
- Stress analysis
- Puncture analysis
- Wind uplift analysis
- Anchor trench design
- Subsurface consolidation design
- Slope stability analysis

- Leachate Collection and Recovery System (LCRS) design
- Leak Detection and Recovery System design
- Frost protection analysis.

The design tasks identified for the ICDF landfill permanent cover are as follows:

- Surface slope and erosion protection
- Settlement analysis
- Side slope erosion protection design
- Slope stability analysis
- Evapotranspiration component design
- Biointrusion component design
- Lateral drainage analysis
- Stress analysis
- Puncture analysis
- Wind uplift analysis
- Anchor trench design
- SBL design (same as liner)
- Filter design
- Vegetation design.

For each design and analysis task, the associated applicable or relevant and appropriate requirements (ARARs) and performance design criteria were defined, and the appropriate design calculation completed. These calculations are either referenced in other design studies provided under a separate cover or provided in one of the calculation packages included as appendices to this document. This study also includes an explanation of how the design analyses consider the required liner and cover service life. Explanations are provided to demonstrate how the permanent cover system will meet the minimum design life of 1,000 years and conceivably perform beyond its design life. The detailed infiltration modeling of the final cover is provided under a separate cover in the hydrogeologic model of the final cover design study (EDF-ER-279).

# 1.2 Regulatory and Performance Requirements

## 1.2.1 Applicable or Relevant and Appropriate Requirements

The Performance Specifications for the ICDF landfill and evaporation pond (SPC-332) describe the performance and other requirements for the liner and cover system. Specifically, the ICDF landfill and evaporation pond design need to meet all ARARs, which include the substantive requirements listed below:

- Comply with the substantive requirements of the Resource Conservation and Recovery Act (RCRA) Subtitle C design standards specified in Idaho Administrative Procedures Act (IDAPA) 16.01.05.008 (40 Code of Federal Regulations [CFR] 264.301 and 40 CFR 264.302) and the polychlorinated biphenyls (PCB) Chemical Waste Landfill Design requirements (40 CFR 761.75).

- Comply with the substantive requirements of RCRA Subtitle C closure requirements specified in IDAPA 16.01.05.008 (40 CFR 264.310), which include the following:

  - Provide long-term minimization of migration of liquids through the closed landfill.

  - Function with minimum maintenance.

  - Promote drainage and minimize erosion or abrasion of the cover.

  - Accommodate settling and subsidence so that integrity of the cover is maintained.

  - Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.

  - Maintain the integrity and effectiveness of the final cover, including making repairs to the cover as necessary to correct the effects of settling, subsidence, erosion, or other events.

  - Maintain and monitor the groundwater monitoring system.

  - Prevent run-on and run-off from eroding or otherwise damaging the final cover.

  - Protect and maintain surveyed benchmarks used in complying with 40 CFR 264.309.

## 1.2.2 Record of Decision Design and Operating Objectives

The ICDF Complex must also comply with the design and operating objectives identified in the Record of Decision (DOE-ID 1999a). These objectives are listed below:

- Maintain the cover placed over the closed ICDF landfill, to prevent the release of leachate to underlying groundwater, which would result in exceeding a cumulative carcinogenic risk of $1 \times 10^{-4}$, a total Hazard Index (HI) of 1; or applicable State of Idaho groundwater quality standards (i.e., maximum contaminant levels [MCLs]) in the Snake River Plain Aquifer (SRPA).

- In 2095, and beyond, ensure that SRPA groundwater does not exceed a cumulative carcinogenic risk of $1 \times 10^{-4}$; a total HI of 1; or applicable State of Idaho groundwater quality standards (i.e., MCLs).

- Minimize precipitation run-on and maximize precipitation run-off to effectively reduce infiltration through the contaminated soils and debris.
- Minimize subsidence of the waste and landfill cap.
- Ensure that the design is protective of human and ecological receptors.
- Ensure that the final cover is designed to serve as an intrusion barrier for a period of at least 1,000 years.

# 2. LANDFILL AND EVAPORATION POND LINER DESIGN ANALYSIS

The ICDF landfill and evaporation ponds will be lined with a double composite liner system with leak detection to minimize and detect percolation of liquids into the subsurface. The composite landfill liner system consists of a primary high-density polyethylene (HDPE) geomembrane/geosynthetic clay liner (GCL) composite barrier and secondary HDPE geomembrane/SBL barrier. The evaporation pond liner system consists of two HDPE/GCL composites. Leakage rate studies at existing landfills with composite barrier systems compared to landfills that have single liner systems show a significant reduction in leakage rate. Moreover, leakage rate studies at existing landfills with composite liners comprised of a HDPE geomembrane and GCL show average leakage rates as low as 1 gallon/acre/day through the primary liner system (Bonaparte et al. 1999).

Between the primary and secondary barriers will be a drainage material to detect leaks from the overlying primary barrier and divert the liquid to a main sump. Liquids in the sump can be removed by pumps through riser pipes installed in the landfill and evaporation pond. The primary leak detection recovery system (PLDRS) has been designed with a high transmissivity so that liquids can flow with little resistance to a central sump. Both the landfill and evaporation pond will contain a PLDRS.

The ICDF landfill will also include a secondary leak detection recovery system (SLDRS) located directly beneath the lowest barrier, which is the SBL. The SLDRS is positioned above a tertiary HDPE geomembrane located beneath the center of the landfill. Liquids would have to pass through two HDPE geomembranes, a GCL, and a 3-ft-thick low-permeable SBL before being detected in the SLDRS. The SLDRS will provide vadose zone monitoring and early detection.

Leachate generated in the landfill will be managed with a LCRS. The LCRS consists of high-permeable gravel overlying the primary HDPE geomembrane on the landfill floor and a synthetic geocomposite material on the side slopes. The LCRS will divert leachate to a perforated pipe located along the center north-south axis of the landfill. Leachate then flows through the pipe to the LCRS sump where it can be pumped to the evaporation pond.

The ICDF and evaporation pond lining system meet or exceed the requirements of RCRA Subtitle C design standards specified in IDAPA 16.01.05.008 (40 CFR 264.301 and 40 CFR 264.302) and the PCB Chemical Waste Landfill Design requirements 40 CFR 761.75. A profile of the landfill and evaporation pond liner systems is provided in Figures 2-1 and 2-2, respectively.

For each liner system component, its function, life cycle, and design basis were evaluated. The liner system function of a liner component is used to develop the design criteria and life cycle. Each components' life cycle is defined by the stages used below:

- Stage 1—Construction and first year active life
- Stage 2—Active life, years 2 to 15
- Stage 3—Post-closure life, years 15 to 45
- Stage 4—Long-term life, years 45 to 1,000.

The design basis includes the design criteria and summarizes the design results. Design calculations are either referenced in the appropriate engineering study or in an appendix of this document.

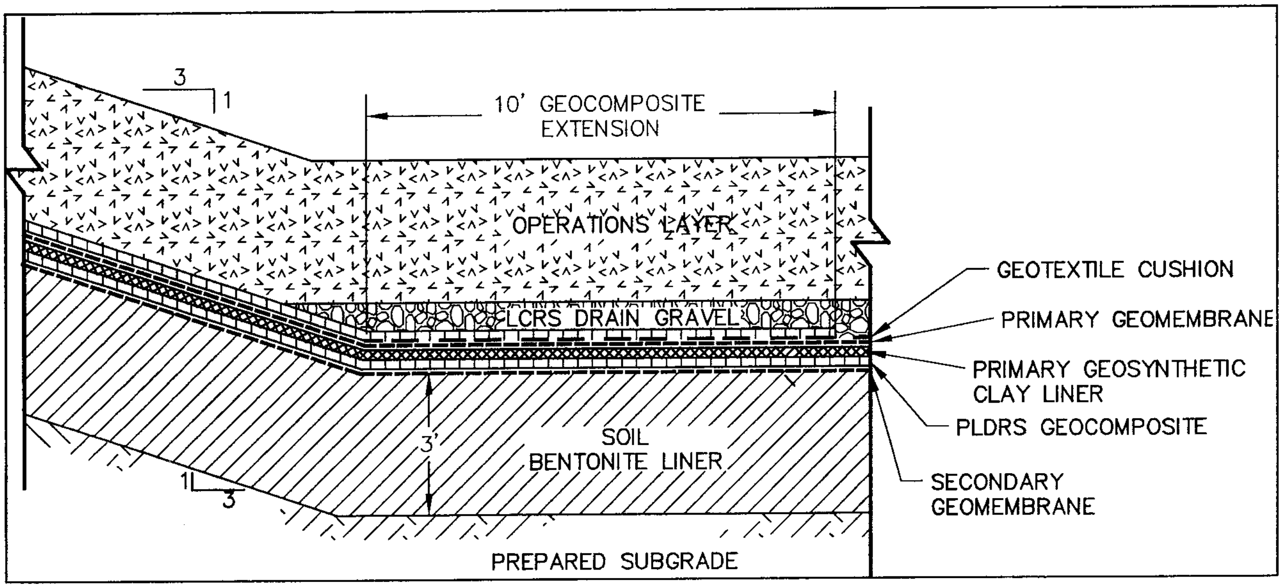


Figure 2-1. Landfill double composite liner system.

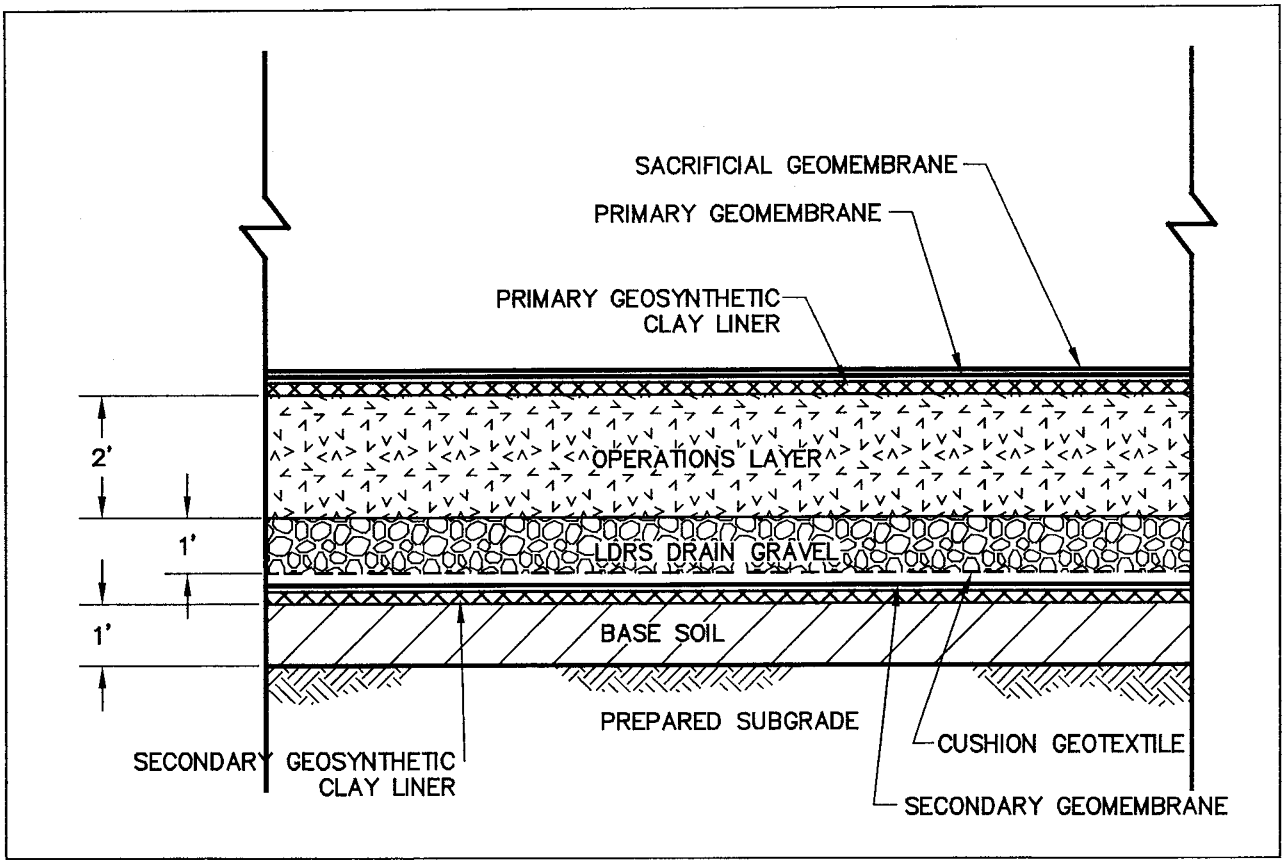


Figure 2-2. Evaporation pond double composite liner system.

# 2.1 Barrier Layers

## 2.1.1 Function

The barrier layer can have three functions depending on its placement in the liner system. First, it can be the primary barrier to keep leachate from leaking into the underlying PLDRS. Second, it can provide a secondary barrier to provide a means of identifying a leak from the primary system. Third, it can provide an absorptive capacity of contaminants as a SBL. The composite liner system (i.e., primary geomembrane/GCL and secondary geomembrane/SBL) provides an added protection from leaks. The lower liner at the composite will mitigate leaks from the upper layer, reducing flow through a hole or defect by keeping the hole or defect from becoming larger over time.

## 2.1.2 Life Cycle

The life cycle of the barrier layers in the liner system include Stages 1 through 4. The barrier layers will perform their function through the ICDF landfill post-closure life. Thereafter, it is unknown if the synthetic portions of the barrier system will remain intact since the performance of these materials has only been monitored for the last several decades. Even if the HDPE geomembranes degrade after the post-closure life, the earthen components of the barrier system will remain, including the 3-ft-thick SBL and thin layer of bentonite in the GCL. Fate and transport modeling has shown that with the synthetic barriers absent, including the bentonite from the GCL, the ICDF landfill liner continues to be protective of the SRPA throughout its long-term life (EDF-ER-275).

## 2.1.3 Design

***2.1.3.1 Soil Bentonite Liner.*** The SBL was designed to have a maximum saturated permeability of $1 \times 10^{-7}$ cm/sec. Studies of SBLs have shown that this permeability significantly reduces the amount of percolation (Peyton and Schroeder 1990).

The permeability of the local clay borrow ranges from $1 \times 10^{-6}$ cm/sec to $1 \times 10^{-7}$ cm/sec (DOE-ID 2000). A soil amendment study was performed to determine the amount of bentonite needed in the clay to achieve the permeability requirement in the laboratory (EDF-ER-272). The study concluded that mixing the clay borrow (i.e., base soil) with 5% of bentonite by dry weight produced a SBL material having a maximum permeability of $1 \times 10^{-8}$ cm/sec in the laboratory.

***2.1.3.2 Compatibility.*** A liner/leachate compatibility study was performed to compare the expected composition of the leachate with compatible limits for the individual liner materials (EDF-ER-278). The leachate constituent concentrations were compared to the results of previous compatibility studies and manufacturers' recommended maximum concentrations to determine compatibility. Based on the literature, the leachate will be compatible with the geomembrane, GCL, and SBL components. The manufacturers' compatibility data and published compatibility tests were reviewed to suggest maximum leachate limits for individual constituents to determine WAC with regard to liner compatibility. These leachate limits were used to determine the maximum allowable waste soil concentrations that, if placed in the ICDF landfill, would not cause significant degradation of the liner system.

A review of compatibility studies performed for other hazardous waste that accept low-level radioactive materials showed that the HDPE liner only had a slight reduction in tensile strength and elasticity after it was irradiated with a total dose of 1,000,000 rads. The anticipated dose to the primary geomembrane in the ICDF landfill and evaporation ponds are 12,000 rads and 1000,000 rads, respectively, during their operational life (EDF-ER-278).

***2.1.3.3 Stress Analysis.*** Stresses will be induced in the liner barrier components due to settlement in the foundation soils. The settlement of the foundation soils is estimated to be 1.2 ft (EDF-ER-266). Settlement will elongate the synthetic materials and potentially crack the SBL. Worst-case stresses were calculated for the geomembrane, GCL, and SBL components based on settlement occurring at the toe of the landfill side slopes. The results of the analysis indicate a factor of safety (FS) of over 100 against rupture. The liner system stress analysis is provided in Appendix A.

***2.1.3.4 Puncture Analysis.*** The primary geomembrane liner will be subject to puncture from the LCRS gravel loaded by waste material and the cover. A non-woven geotextile will be installed between the geomembrane and LCRS gravel to provide a cushion. The suitability of the cushion geotextile was evaluated using two methods. In the first method, the required puncture resistance of the geotextile was determined based on the particle size distribution of the LCRS gravel and loads generated by the waste and cover system. The round alluvium sand and gravels excavated from the landfill will be screened to remove particles over 2 in. in diameter for the LCRS. Grain size analysis performed on the screened LCRS gravel indicate an average particle size ($D_{50}$) of 15 millimeters. The factor of safety using this method was 3.9 for a 12 ounce per square yard non-woven geotextile fabric. The puncture analyses are provided in Appendix B. The second method calculates an allowable pressure based on geotextile mass per unit area. Comparing the actual pressure of the waste and cover system to the calculated allowable pressure results in a minimum factor of safety of 3.6 based on a 12 ounce per square yard non-woven geotextile. A sensitivity analysis was performed to evaluate the impacts of increased protrusion height and shape factors of the LCRS gravel. A protrusion height of 25 mm (which is one half of the maximum particle size) resulted in a factor of safety of 1.8, which is less than the recommended factor of safety of 3.0. The protrusion height that resulted in the reduced safety factor in this analysis is not realistic based on the site-specific data for the LCRS gravel. These analyses are provided in Appendix B.

***2.1.3.5 Wind Uplift.*** Geomembranes, and to a lesser extent GCLs, are susceptible to wind uplift causing damage prior to placing overlying soil layers. The landfill will be covered with operations material after the liner system is installed, protecting from wind uplift. The evaporation ponds will contain water during their operation to subdue dust that will also anchor the geomembrane. However, there will be short periods of time when the geomembranes will be exposed to winds such as during the liner installation and during periods of evaporation pond maintenance. The wind uplift analyses and suggested anchor spacing are provided in Appendix C.

***2.1.3.6 Anchor Trench.*** The geomembranes, GCL, and other synthetic materials comprising the lining system will be terminated in trenches constructed around the perimeter of the landfill and evaporation ponds. The ends of the liners will be buried under 2 ft of earth to protect from wind uplift and pull out. The pull-out analysis for the anchor trench is provided in Appendix D.

***2.1.3.7 Subsurface Consolidation.*** The existing sand and gravely foundation soils will provide a structurally stable subgrade for the ICDF landfill liner system. Additionally, the foundation layer is relatively thin, dense, and is not influenced by a changing groundwater table. The soils underlying the landfill consist of a relatively thin layer of dense alluvial deposits overlying basalt bedrock ranging in thickness from 15 to 25 ft. The alluvium consists of gravels, gravel-sand mixtures, and sand-gravel-cobble mixtures to poorly sorted gravels with sand and silt. An intermittent layer of fine sand, silt, and clay (i.e., "old alluvium") between the bedrock and gravels ranges in thickness from 2 to 7 ft based on the borings located within the landfill footprint. Groundwater is located approximately 440 ft below the landfill bottom (EDF-ER-275).

The subsurface consolidation study (EDF-ER-266) provides an estimate of the maximum long-term settlement that is used to determine differential settlement in the landfill liner system. This analysis takes into account the loading due to the waste material in the landfill and the cover. The stresses in the soil bentonite and the synthetic liners caused by the maximum differential settlement were calculated and compared to allowable stresses to determine the ability of the liners, PLDRS, and LCRS to maintain their integrity.

The maximum total settlement at the center of the landfill is conservatively estimated to be 1.2 ft. Differential settlement is a function of the maximum total settlement and will be less than the total settlement; however, it is difficult to estimate. So, as a worst case, the maximum differential settlement was assumed to be equal to the maximum total settlement of 1.2 ft. Stresses in the liner materials (i.e., geomembranes, GCL, SBL, and leachate collection piping) were determined at the toe of the landfill side slope described in Section 2.1.3.3 and at the center of the landfill described in the subsurface consolidation study. The strain caused by the stresses in either location were significantly below allowable values for the individual liner materials.

***2.1.3.8 Slope Stability.*** Slope stability evaluations were performed to determine the stability of the liner system and waste mass in the landfill during excavation and during operation. Stability evaluations included stability after excavation, veneer stability once the liner system is in place, and global stability. The first category involves evaluation of stability immediately after excavation of the landfill but before placement of the lining system. Veneer stability involves evaluation of the potential for sliding of the drainage and operations layers on the liner system before refuse is placed. Global stability involves evaluation of the potential for sliding after refuse is placed and after placement of the final cover (that is, the final landfill configuration). In the global stability analysis, the refuse mass can potentially slide on a plane through the refuse, on the lining system, or on some combination of the two.

For the global stability analysis, earthquake loading was modeled using a pseudo-static method. This procedure is similar to a static slope stability analysis except that the effect of earthquake loading is added as a horizontal inertial force acting at the centroid of the critical sliding mass. For veneer stability, the minimum FS was determined using the traditional sliding-block analysis by including anchorage forces, seepage forces, equipment loads, and the effect of toe buttressing. Earthquake loading is treated as a pseudo-static force (equal to the soil weight and multiplied by a seismic coefficient, k) acting parallel to the slope. The peak acceleration used for the earthquake loading was based on a DOE Performance Category (PC) 4. This PC is a high-hazard category for a magnitude of an earthquake that would have a reoccurrence interval of 1 in 10,000 years.

The FS met or exceeded the minimum required values, which are either based on specific regulations or the standard of practice. Based on the stability analyses, the following conclusions and guidelines for waste placement operations and practical construction/maintenance considerations are provided below:

- The proposed design side slopes for the ICDF landfill and evaporation ponds satisfy the minimum requirement for stability for the range of loading conditions evaluated in this report.
- Site-specific interface shear strength tests were performed on the actual products and materials selected for use on the project. The results of the test indicate a higher interface friction than used in the stability calculation.
- No anchorage forces for the side slope liner are required to achieve required minimum FS for veneer stability.
- The proposed design for evaporation ponds satisfies the minimum requirements for global stability.
- The final landfill configuration is stable under both static and seismic loading.

The slope stability analyses are provided in the slope stability assessment and seismic evaluation of landfill and evaporation pond studies (EDF-ER-268 and EDF-ER-282).

***2.1.3.8 Freeze-Thaw Analysis.*** SBL can sustain irreversible damage caused by freeze-thaw cycles. Water added during construction for compaction can freeze, increasing the permeability through formation of cracks, microcracks, and interconnected macro pores (Benson and Othman 1993). The GCL in the landfill and evaporation pond lining system will be less susceptible to damage caused by freeze-thaw cycles (Krause et al. 1997).

Extreme frost penetration at INEEL is estimated to be 45 in. The ICDF landfill SBL and GCL barrier layers will be protected from frost by a 48-in.-thick layer of soil comprised of the 12-in.-thick leachate collection gravel and 36-in.-thick operations layer on the landfill floor. The barrier layers on the landfill side slopes will be protected by the 36-in.-thick operations layer. The secondary GCL barrier in the evaporation ponds will be protected by a 36-in. layer of soil sandwiched between the primary and secondary liners as shown in Figure 2-2. Permanent frost protection will be provided by the waste after it is placed in the landfill. Additional frost protection will be provided by the overlying geosynthetics such as the HDPE geomembranes and geocomposites in the landfill and evaporation ponds. The freeze-thaw analysis is provided in Appendix I.

***2.1.3.9 Equipment Loading/Wheel Loading Ground Pressure Analysis.*** The evaluation of the ground pressures on the geosynthetic components of the liner system was based on the equipment expected to be used during construction of the liner system. The analysis, presented in Appendix J, indicates that, when placed over the geosynthetic components, the cover material (at the thickness required in the specifications and shown in the drawings) provides adequate protection against damage from equipment loads.

## 2.2 Leachate Collection

The ICDF landfill will include a LCRS located above the primary geomembrane liner. The LCRS will consist of a high-permeable gravel layer on the landfill floor and a high transmissive geocomposite on the side slopes. A center drain comprised of a perforated pipe allows leachate to quickly flow to the LCRS sump. Liquids in the sump are removed by pumps through riser pipes. The landfill floor is sloped toward the center drain and sump to promote drainage.

The ICDF landfill LCRS meets or exceed the substantive requirements of RCRA Subtitle C design standards specified in IDAPA 16.01.05.008 (40 CFR 264.301 and 40 CFR 264.302) and the PCB Chemical Waste Landfill Design requirements 40 CFR 761.75. The function, life cycle, and design of the liner system barriers, leachate collection, and leak detection is provided in the follow sections.

### 2.2.1 Function

The primary function of the LCRS is to minimize the hydraulic head over the primary geomembrane liner to less than 1 ft measured at the lowest point in the landfill (e.g., sump). The LCRS must be free draining without clogging so that leachate can quickly drain to the sump so that it can be removed from the landfill.

### 2.2.2 Life Cycle

The life cycle of the LCRS includes Stages 1 through 3. The LCRS will perform its function through the ICDF post-closure life (i.e., Stage 3). Leachate will be generated as a result of precipitation over the open landfill and water added to the waste for operational purposes. Leachate volume will be its greatest with a diluted concentration of leachate constituents during Stage 1. Any fine-grained material left in the LCRS is flushed through the system during this time. As waste is placed in the landfill, leachate volume will reduce with a higher concentration of leachate constituents during Stage 2. During Stage 3, leachate volume will substantially decrease once the landfill cover is constructed. At Stage 4, leachate production will be reduced to insignificantly small volumes, eliminating the need for a LCRS system. If needed, however, the LCRS system could continue to function during Stage 3.

### 2.2.3 Design

The LCRS design consisted of sizing the LCRS based on expected precipitation event and leachate generation to maintain less than 1 ft of hydraulic head over the liner system. Leachate composition was determined to evaluate liner compatibility and WAC. The LCRS design is provided in the three design studies listed below:

- EDF-ER-269—Leachate Generation Study
- EDF-ER-280—Landfill Leachate Collection System Design Analysis
- EDF-ER-274—Leachate/Contaminant Reduction Time Study.

Leachate from the ICDF landfill will be managed using evaporation ponds. The design of the facility is such that leachate formed in the ICDF will be conveyed to the evaporation pond system that consists of twin lined ponds where contaminant residue or sludge will precipitate from the liquid as it evaporates.

The leachate generation study was first used to estimate the amount of leachate that would be generated during operation of the ICDF on an annual basis. The design was based on the period of operation for the evaporation pond system that includes the 15-year active life of the ICDF cell, as well as the 30-year post-closure operating time period or until leachate is no longer generated. The active life of the pond system represents the period in the landfill life where maximum leachate can be expected. This is when the landfill is open (prior to placement of final cover) and is actively receiving waste. Leachate generation will decrease once the permanent barrier cover is placed over the waste mass due to a reduced infiltration rate. During the post-closure time period, the evaporation ponds will be available to handle the small quantities of leachate that would be generated from the waste mass. A conservative approach was used for estimating the leachate generation volumes to ensure that ponds are conservatively sized for handling a variety of inflow conditions.

The leachate collection system was then designed using the anticipated flow rates determined in the leachate generation study. The primary criterion is that all leachate be collected and removed from the landfill at a rate sufficient to prevent a hydraulic head greater than 12 in. from occurring at any point over the lining system. The design basis of the leachate collection system is provided below:

- Bottom of the leak detection layer is sloped at >1%.
- Granular drainage layer is 1-ft thick with hydraulic conductivity $>1 \times 10^{-2}$ cm/s.
- The system must be designed to minimize clogging.
- The system is designed to maintain runoff from a 25-year, 24-hour storm.
- Sumps and liquid removal system are of sufficient size to prevent back-up into the drainage layer.

System components that come into contact with waste are chemically resistant to the waste and have sufficient strength and thickness to resist collapse. The design analysis is provided in the landfill leachate collection system design study (EDF-ER-280).

Lastly, concentrations of selected design inventory constituents in the ICDF landfill leachate were simulated over the 15-year operations period and 30-year post-closure period in the leachate/contaminate reduction time study. The purpose of this study was to examine the change in leachate concentration over time, as it is directed toward the evaporation pond, and determine its geochemical properties. The results were used to determine liner compatibility (EDF-ER-278).

## 2.3 Leak Detection

Between the primary and secondary barriers in the ICDF landfill, there will be a synthetic geocomposite material to collect leaks from the overlying primary barrier and direct the liquid to the central sump for detection and removal. The PLDRS had been designed with a high transmissivity so that any liquids can flow to the central sump. The evaporation ponds will also contain a PLDRS comprised of a 1-ft-thick layer of gravel having a minimum permeability of $1 \times 10^{-1}$ cm/sec. Gravel was selected for the evaporation pond instead of a geocomposite to provide added frost protection.

The ICDF landfill will also include a SLDRS located directly beneath the lowest barrier, which is the SBL. The SLDRS is positioned above a tertiary HDPE geomembrane beneath the center of the landfill. Liquids would require passing through two HDPE geomembranes, a GCL, and a 3-ft-thick low-permeable SBL before detection in the SLDRS. The SLDRS will provide vadose monitoring and early detection of leaks into the vadose zone from the landfill.

The landfill and evaporation pond PLDRS meets or exceeds the substantive requirements of RCRA Subtitle C design standards specified in the IDAPA 16.01.05.008 (40 CFR 264.301 and 40 CFR 264.302) and the PCB Chemical Waste Landfill Design requirements 40 CFR 761.75.

### 2.3.1 Function

The function of the PLDRS is to detect a leak in the overlying layers in a reasonably short amount of time. The PLDRS also provides a system to recover liquids that may pass through leaks in the overlying primary barrier layers. The SLDRS provides a redundant system and early detection of leaks through the primary and secondary barrier layers prior to reaching the SRPA. It is strategically located beneath the center drain and sump of the landfill where leaks in the barrier layers would have the highest probability of allowing leachate to penetrate the liner system.

### 2.3.2 Life Cycle

The life cycle of the PLDRS and SLDRS includes Stages 1 through 3. The PLDRS and SLDRS will perform their function through the ICDF post-closure life. The highest probability of leaks occur during Stage 1 when the initial layers of waste are being placed. During this time, there is a higher risk for damage to the primary geomembrane, mostly due to heavy equipment placing waste near the liner. The PLDRS will also produce a small volume of water during Stage 1 that is left in the system during construction. Water is also expected from the SLDRS due to consolidation of the SBL as it is loaded by the waste. The PLDRS and SLDRS will be monitored on a regular basis during Stages 2 and 3 in accordance with the ICDF operation and maintenance plan (DOE-ID 2001). Predefined response actions will be performed if liquids in the PLDRS exceed the action leakage rate. Leachate production is expected to significantly decrease during Stage 3 once the landfill is covered. Monitoring activities will continue, however, the probability of new leaks being produced during this time is low. At Stage 4, leachate production will be reduced to very small amounts eliminating the need for a PLDRS and SLDRS system, although, these systems may continue to function during this time if needed.

### 2.3.3 Design

**2.3.3.1 *Leak Detection Recovery Systems.*** The design of the PLDRS is provided in the Leachate Collection System analysis (EDF-ER-280). The design also includes the action leakage rate. The response plan is provided in the ICDF operation and maintenance plan (DOE-ID 2001). The Action Leakage Rate (ALR) is defined in the Final Rule 40 CFR Part 264.302, as the "maximum design flow rate that the leak detection system can remove without the fluid head on the bottom liner exceeding 1 ft." The recommended EPA ALR value of 100 gallons/acre/day for landfill was used for the design analysis. Based on this leakage rate, the ALR for the ICDF landfill cell is 1,380 gallons per day and includes a FS of 2 in accordance with EPA guidelines. This result formed the basis of the PLDRS design including the PLDRS sump and pump size requirement.

The PLDRS will perform during the 15-year active life of the ICDF cell, as well as the 30-year post-closure operating time period. The active life of the landfill represents the period in the landfill life where maximum leachate and leaks can be expected. The leachate and corresponding leakage rate will be reduced by placement of the permanent cover barrier. During the post-closure time period, the PLDRS will be available to detect and collect leachate if a leak were to occur.

The purpose of the SLDRS is to provide a system for quickly identifying any potential leaks from the ICDF landfill in the areas of greatest leachate accumulation. This SLDRS will be part of the vadose zone monitoring system intended to supplement the deeper groundwater monitoring program that exists for this area of the INEEL.

The SLDRS will consist of a gravel drain and perforated HDPE pipe placed directly beneath the bottom SBL that is sloped to a central sump. The sump provides access to any liquid collected in the SLDRS for removal and analysis. The SLDRS will be placed in a limited aerial extent only in the region of greatest probability of leachate collection and bottom liner leakage. The greatest probability of bottom liner leakage will be near the LCRS sump. The hydraulic head is usually the greatest over the liner near the LCRS sump and the greatest density of seams in the geomembrane usually occurs at this location. Because the SLDRS will be placed directly beneath and in contact with the bottom liner of the landfill, water capture in the SLDRS sump will be almost exclusively from leaks through the liner system. The SLDRS will be extended under the center of the landfill along its north-south axis. This region would be the second greatest probability of bottom liner leakage. However, since a partial SLDRS will be installed, there is some possibility that perched water outside of the landfill cell could seep in along its edges. For this reason, chemical analysis of any water captured in the SLDRS sump will be used to distinguish between leaks and outside groundwater influences.

Underlying the gravel drain will be a tertiary HDPE geomembrane approximately 22 ft in width that extends the entire length of the central drainage area in the middle landfill cell. In addition, the tertiary geomembrane will be constructed under the entire sump area. Figure 2-3 illustrates the footprint of the tertiary liner system. In the initial construction phase, the tertiary geomembrane will be built to the extent of the central drainage area in Cell 1. The SLDRS can be easily extended to cover the central drainage area across Cell 2 in the future. Following the slope of the bottom of the cell, the SLDRS will drain to a leak monitoring sump near the LDRS sump. The geomembrane will be used as the barrier layer to direct leakage into the collection system. Drain sand will be used to cover the collection system for protection of the system from the overlying SBL construction. The collection sump for the SLDRS will be located directly beneath the LDRS collection sump.

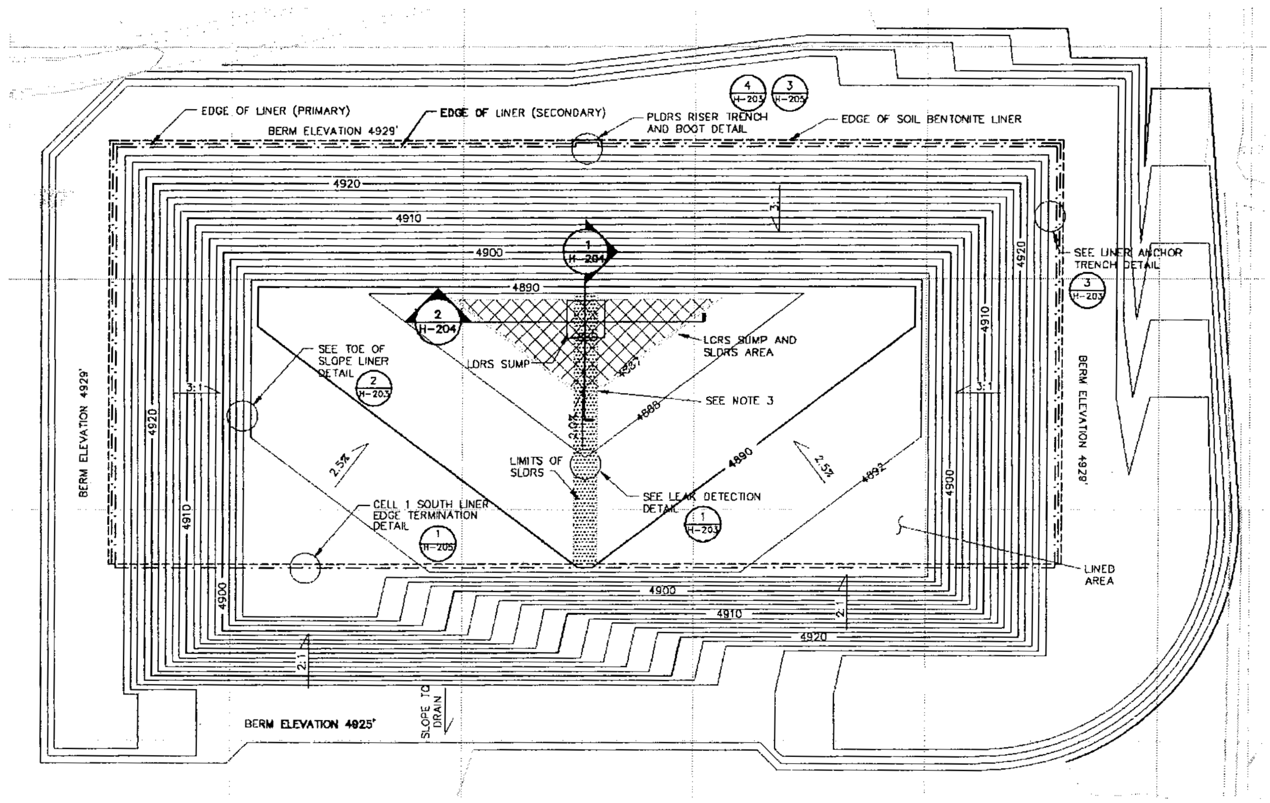


Figure 2-3. Tertiary liner footprint.

The SLDRS sump will be regularly inspected for any collected fluids. In the case of fluid capture, all fluids will be pumped out of the sump and tested for selected indicator parameters. In the case that indicator parameters are present, a full chemical analysis would be completed on the liquids. In the event that indicator parameter concentrations exceeded the baseline concentrations established in the soil pore water from the SLDRS, an investigation would be conducted to determine the source of the contaminants of concern and to propose corrective action. Notably, as the SLDRS is located directly beneath the SBL, construction pore water is expected to squeeze out of the SBL due to waste loading, and collected in the SLDRS.

Using a chemical screening of the waste soil materials to be placed in the landfill, indicator parameters would be chosen for the monitoring program. Two prevalent radionuclides in the waste soil material are iodine-129 and tritium. Both of these species are very mobile in the subsurface environment, and may also be used as indicators. Results of ongoing leachate sampling would be reviewed through the operation of the ICDF landfill and indicator parameters would be periodically reevaluated. Following installation, the SLDRS would be sampled regularly for the indicator parameters. In the event that indicator waste constituents were present in quantities exceeding baseline concentrations, a more detailed chemical analysis would be completed on the liquids.

The PLDRS monitoring system data would be used in the objective and critical analysis of leak detection data and groundwater monitoring data obtained from the ICDF. The data would be used in conjunction with the SLDRS data to determine the following:

1. That the liner systems are functioning as designed

2. Whether a leak has occurred within the ICDF

3. To what extent a leak has extended (has it left cell confinement?)

4. What the potential location and source of the leak could be, or what source of other site contamination could be impacting monitoring points

5. To what extent any response actions are necessary, and how effective they might be once implemented. Specific response actions are described in the Operations and Maintenance Plan (DOE-ID 2001). As noted, the SLDRS will operate through the post-closure period and will provide data that can be used to conclusively identify the source of any detected problems.

# 3. LANDFILL COVER DESIGN ANALYSIS

The ICDF landfill will be capped with a robust state-of-the practice cover barrier to minimize long-term infiltration. The cover system will meet the remedial action objectives to minimize infiltration and maximize run-off and protect against inadvertent intrusion for minimum of a 1,000 years and meet ARARs under the IDAPA and RCRA Subtitle C requirements for closure of a hazardous waste landfill.

The cover system will minimize infiltration and maximize run-off by maintaining a sloped surface, storing water for later release to the atmosphere, lateral drainage, and providing a low-permeability composite liner barrier system. The cover can be divided by function into three main sections. Each section and its function are listed below:

- Upper section: The upper water storage component provides water storage during wet periods for later release into the atmosphere during dry periods.

- Middle section: The biointrusion provides protection from burrowing animals and a capillary break.

- Lower section: The lower section includes a composite liner system that has a permeability less than or equal to the permeability of the landfill bottom liner system that complies with IDAPA 58.01.05.008 [CFR Part 264.310]. Lateral drainage can occur above the composite liner system through a high-permeability drainage material.

Each component in the cover profile is shown in Figures 3-1 and 3-2.

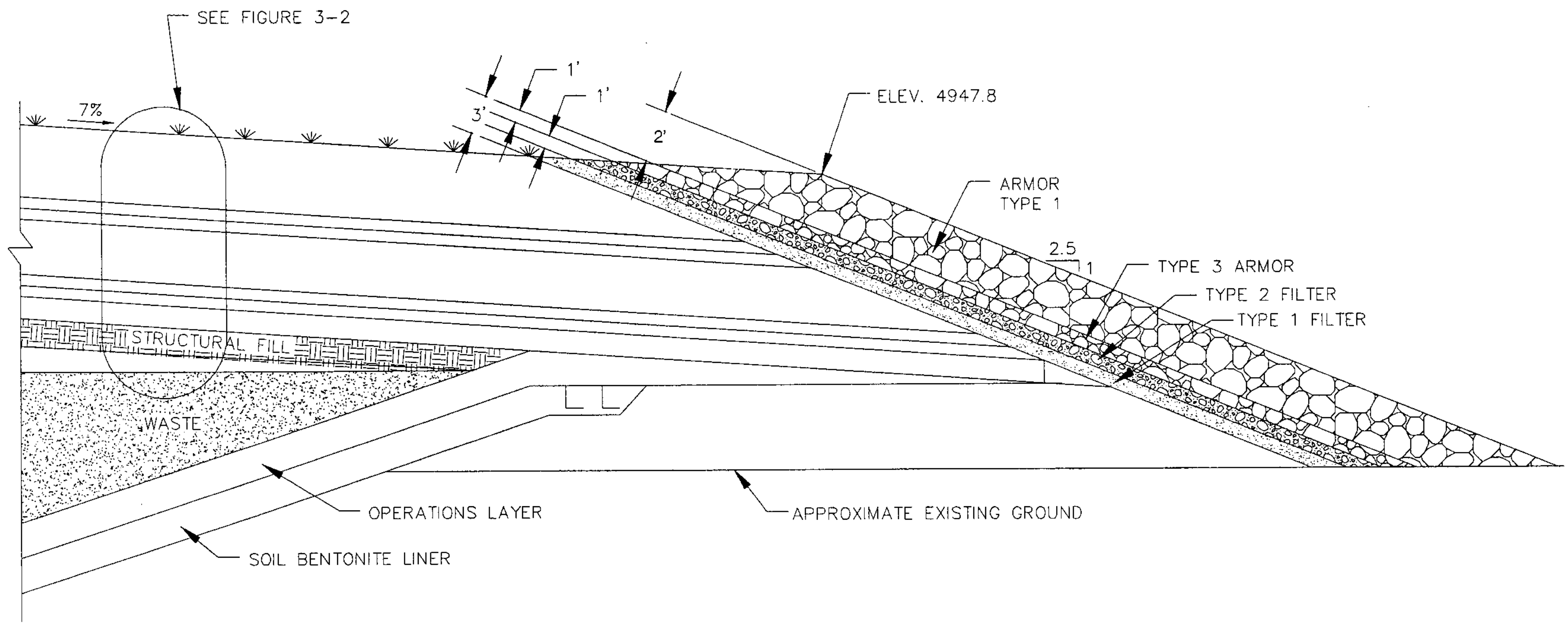


Figure 3-1. Landfill cover section.

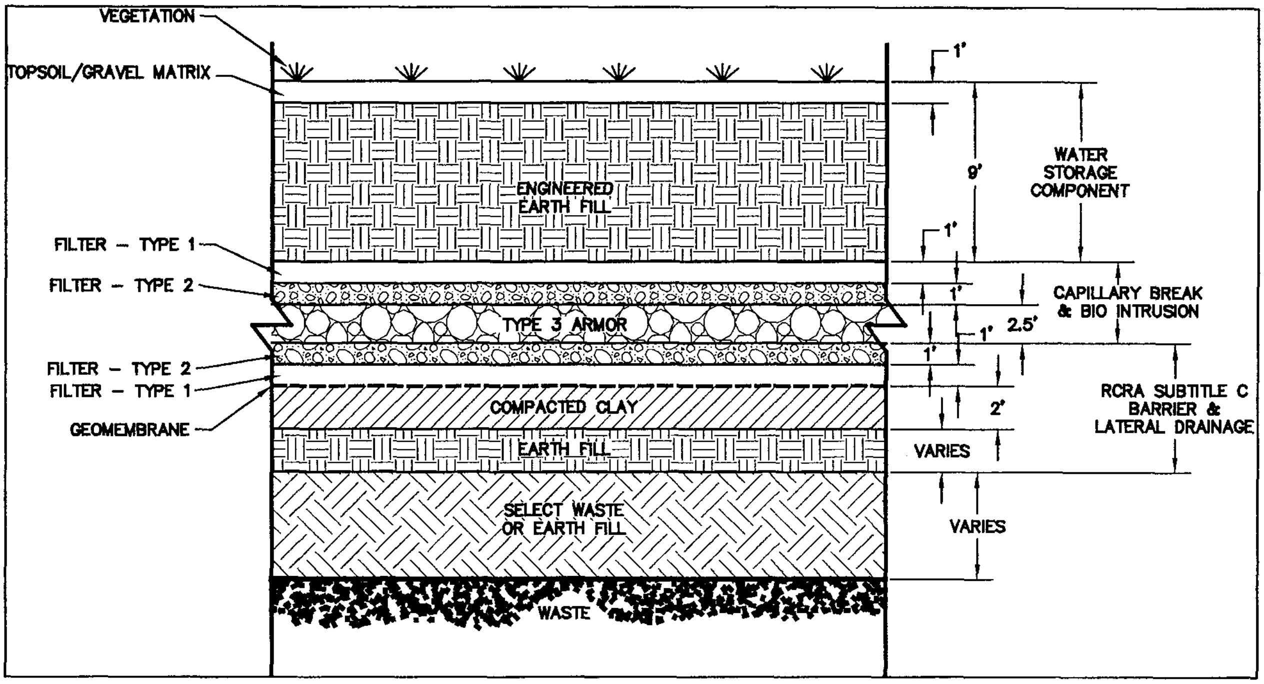


Figure 3-2. Landfill cover profile.

The function, life cycle, and design basis of each cover system component are provided in the following sections.

## 3.1 Cover Surface Grade and Erosion Protection

The top surface of the cover will consist of a vegetated soil/gravel matrix system sloped to minimize infiltration and maximize run-off. Vegetation will enhance the evapotranspiration properties of the upper cover portion and provide erosion control. The soil/gravel matrix will prevent excessive soil loss due to wind and surface water run-off. The design of the cover surface and erosion protection is a combination of ICDF site-specific studies and off-site studies performed at the Hanford facility to support the development of long-term protective covers.

The ICDF landfill cover surface grade and erosion protection meets or exceed the requirements of RCRA Subtitle C design standards specified in IDAPA 16.01.05.008 (40 CFR 264.301 and 40 CFR 264.302). It is designed to provide long-term minimization of migration of liquids through the closed landfill, function with minimum maintenance, and minimize erosion.

### 3.1.1 Function

The function of the surface of the cover is to promote surface water drainage, minimize erosion, and provide a medium for vegetation. The surface will be sloped so that surface water run-off is directed to the side slopes of the landfill lined with basalt riprap armoring. The riprap armor will dissipate eroding forces until it reaches the existing ground surface at a distance of over 100 ft from the edge of the waste mass.

### 3.1.2 Life Cycle

The life cycle of the cover surface includes Stage 1 and Stages 3 and 4. The cover surface and erosion protection is designed to function through the Stage 4 life cycle. During Stages 1 and 3, the cover surface will be maintained, including reestablishing vegetation and maintaining cover grades as necessary. During Stage 4, the vegetation will be well established and erosional issues that were observed in Stage 3 will be corrected. Thereafter, the cover will be periodically monitored as part of INEEL's long term stewardship program and maintained as necessary.

Institutional controls anticipated to be implemented as part of long-term stewardship include the following:

- Access restrictions to prevent intrusions into the closed area, including the creation of a buffer zone surrounding the capped ICDF and supporting structures

- Access controls, monitoring, and maintenance will remain in place for as long as the contents of the landfill remain a threat to human health or the environment if uncontrolled.

### 3.1.3 Design

***3.1.3.1 Cover Settlement.*** The cover settlement has been evaluated in the landfill compaction subsidence study (EDF-ER-267). Based on the settlement determined in this study and the other design considerations (subsidence, erosion, and abrasion) provided herein, a final grade of 7% was determined for the cover. This will ensure that a minimum slope of 3% is maintained after consolidation to promote surface water drainage off the cover system through Stage 4 of its life cycle.

***3.1.3.2 Erosion Analysis.*** Surface water and wind erosion analyses were performed to determine the amount of soil loss from the cover due to sheet flow. Erosion due to surface water was completed using the Modified Universal Soil Loss Equation (MUSLE) as recommended by the Nuclear Regulatory Commission (NRC) for long-term (i.e., 1,000-year) soil loss (NRC 1986). The surface of the cover was assumed to be fine-grained soils such as those found at the Rye Grass Flats area at INEEL without accounting for the protection of the soil/gravel matrix. The analysis consisted of determining the probable maximum precipitation (PMP) event and calculating soil loss per year using the MUSLE equation. Approximately 2 ft of soil could erode from the surface of the cover over a 1,000-year time period. The minimum water storage layer thickness needed to maximize water storage is 6.5 ft based on the Hydrologic Modeling of the Final Cover (EDF-ER-268). The water storage layer will be constructed with an additional 2.5 ft of material to provide a sacrificial layer in the event that the surface would erode due to water erosion. The erosion analysis due to water is provided in Appendix E.

Extensive wind tunnel studies performed at the Hanford facility show that a mixture of fine-grained soil and pea gravel significantly reduced erosion due to wind forces. Soil/pea gravel armoring can reduce erosion rates from 96.5 to more than 99% at wind speeds of 45, 56, and 67 mph (Ligotke 1993). The average wind speed at INEEL based on the period of record is 9 mph with peak gusts up to 82 mph (NOAA 2001). Based on these studies, a soil/pea gravel matrix will provide sufficient protection against wind and aeolian forces for the ICDF cover through Stage 4 of its life cycle, and conceivably beyond.

The potential effects of a 500-year flood event for the Big Lost River was analyzed. Figure 3-3 shows the limits of inundation for a 500-year flood event and the location of the ICDF (DOE 1999b). This figure shows that the ICDF will not be impacted from a 500-year flood event; therefore, scouring of the landfill cover system is not an issue.

As a conservative check, the ICDF landfill was analyzed for the effect of the 500-year flood event flowing past the side slopes. Several important assumptions were made in order to perform this analysis. The first assumption is that the flow rate for the 500-year flood event is 4,100 $ft^3$/sec., the probable 500-year flow rate calculated at the INEEL diversion dam (BOR 1999). The second assumption is that the entire flood volume overtops the banks of the Big Lost River some where upstream of the ICDF facility. The third major assumption is that once the floodwaters overtop the banks of the Big Lost River the entire volume flows past the ICDF landfill. The calculation of the required riprap size for this situation and comparison to the design riprap size is given in Appendix K. The results of this calculation show that there is an FS of 3.4 on the riprap sizing designed for the ICDF cover.

## 3.2 Side Slope Erosion and Stability

The landfill cover side slopes will be sloped at 2.5H:1V (2.5 horizontal to 1 vertical) from the edge of the cover to the existing ground surface as shown in Figure 3-1. The side slopes will be armored with durable basalt rock native to the INEEL area. The rock armor was designed to dissipate erosional forces from surface water run-off and protect the underlying cover layer and waste (note that erosional forces from extreme precipitation events are anticipated to exceed those from flooding events from the Big Lost River as discussed in Section 5.2). The FS against slope failure was determined to verify stability of the side slopes and overall cover system. The side slope erosion protection and stability analysis will ensure that the cover maintains its integrity over the long term.

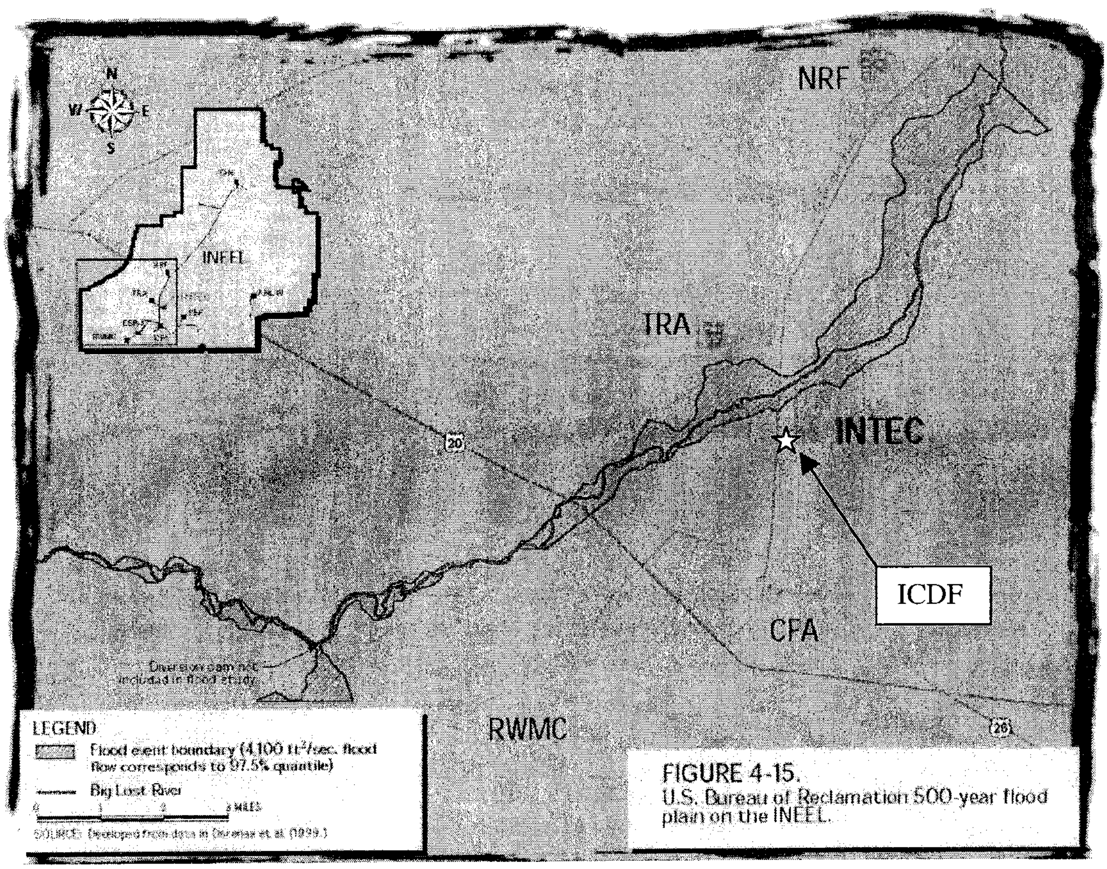


Figure 3-3. Big Lost River 500-year flood plain.

### 3.2.1 Function

The primary function of the side slope armor is to maintain the integrity of the cover system and waste mass. It will dissipate the energy from water run-off from the cover and protect the cover from an unlikely event of a flood. Its secondary function is to provide a biobarrier for the landfill.

### 3.2.2 Life Cycle

The life cycle of the cover surface includes Stage 1 and Stages 3 and 4. The side slope armor will be comprised of earthen materials sized to maintain the cover's integrity through the Stage 4 life cycle.

### 3.2.3 Design

***3.2.3.1 Rock Armor Sizing.*** The rock armor was sized to withstand the hydraulic forces generated by the PMP event. Appropriate testing of the designated material will be performed prior to use. If necessary, the rock armor will be oversized to account for degradation in the long term. Design methods and safety factors for rip rap sizing methods included those recommended by the U.S. Army Corps of Engineers and the NRC for long-term erosion control design. The rock armor sizing analysis is provided in Appendix F.

***3.2.3.2 Cover Slope Stability.*** Slope stability calculations were completed for both static and pseudostatic cases to determine short- and long-term stability. The peak-ground acceleration generated by a DOE PC 4 earthquake was used to ensure pseudostatic stability for the cover performance period. This PC is a high hazard category for a magnitude of an earthquake that would have a reoccurrence interval of 1 in 10,000 years. The cover slope stability is provided in the Slope Stability Assessment (EDF-ER-268).

## 3.3 Evapotranspiration Component

The evapotranspiration component consists of silty loam-type soils that provide water storage during wet periods for later release into the atmosphere during dry periods. Coupled with a capillary break provided by the underlying sand and gravel layers, it will store moisture from long-term, low-probability precipitation events for later release to the atmosphere by evapotranspiration. The evapotranspiration layer in the cover is an integral component that provides long-term minimization of migration of liquids through the closed landfill while functioning for the long term with minimal maintenance.

### 3.3.1 Function

The primary function of the evapotranspiration component is to store and release moisture and provide a medium for plant growth. It also provides a buffer zone between the waste and ecological receptors.

### 3.3.2 Life Cycle

The life cycle of the evapotranspiration component includes Stage 1 and Stages 3 and 4. During Stage 1, the evapotranspiration layer will contain moisture added during construction for compaction and dust control purposes. Some drainage will occur from this layer during the first stage of the cover due to water added during construction. It will reach a pseudo steady-state condition during Stage 3. The cycle will consist of the layer increasing moisture content during the spring snow melt periods followed by periods of drying prior to the next season's cycle. Hydrologic modeling has shown that the evapotranspiration component can recover after cycles of extreme precipitation events and will continue to function through Stage 4 and conceivably years beyond.

### 3.3.3 Design

The thickness of the evapotranspiration layer was determined based on hydrologic modeling provided in the "Hydrologic Modeling of Final Cover" (EDF-ER-279). Sensitivity analysis was performed that determined an optimal layer thickness between 5 and 6.5 ft. The sensitivity analysis shows clearly that increasing the water storage thickness beyond the optimal thickness increases water storage capacity, but does not reduce the percolation rate. Insignificant changes in percolation occur for the water storage layer thickness beyond 6.5 ft. Additional material was added to the water storage layer to address erosion control and aeolian effects described in Section 3.1.3.2.

The material properties used in modeling the hydrologic performance are representative of materials that may be found near the site and will be used during construction of the ICDF landfill cover. The actual hydraulic properties of the materials used during construction will be tested and the model rerun with these data at a later date.

## 3.4 Biointrusion/Drainage

Small animals and insects such as badgers and ants have been known to burrow into landfills, bringing waste materials to the surface and leaving defects in the cover system. Past barrier studies at INEEL, Hanford, and other facilities have shown that a thin layer of gravel is effective in preventing animals and ants from penetrating underlying waste materials (Morris and Bleu 1997; Wing 1993). The ICDF landfill cover will include a Type 3 armor comprised of 2- to 5-in. diameter gravel. The Type 4 armor will also provide lateral drainage in the event breakthrough occurs through the upper cover layers.

### 3.4.1 Function

The primary function of the biointrusion layer is to prevent burrowing animals indigenous to the INEEL area from penetrating the underlying cover components and the waste material. It also provides a high-permeable drainage media if water were to percolate from the upper portions of the cover system.

### 3.4.2 Life Cycle

The life cycle of the biointrusion layer includes Stage 1 and Stages 3 and 4. The biointrusion layer is expected to perform through the Stage 4 life cycle.

### 3.4.3 Design

The biointrusion design was primarily based on review of past studies performed at INEEL. The increase in infiltration due to holes left in the evapotranspiration component were evaluated in the "Hydrologic Modeling of Final Cover Study" (EDF-ER-279). The biointrusion design evaluated both plant and animal intrusion. The summary of the studies is provided in Appendix G. The biointrusion material will consist of gravel screened from the local available alluvium at INEEL. The alluvium gravels at INEEL are composed of granite, quartz, and other durable minerals that make it ideally suited for long-term applications.

## 3.5 Barrier Layers

The primary mechanism for minimizing infiltration through the cover is the upper evapotranspiration cover layer. Barrier layers are included in the lower portions of the cover for redundancy and regulatory compliance. The barrier consists of a single HDPE geomembrane/SBL composite system. Similar to the landfill liner system beneath the waste, the composite system will intercept water in the event breakthrough occurred from upper cover sections and divert it laterally through the overlying sand and gravel layers. The cover barrier layer complies with the substantive requirements of Subtitle C hazardous waste closure specified in IDAPA 58.01.05.008 (40 CFR 264.310) and will have a permeability less than or equal to the permeability of the ICDF bottom liner system.

### 3.5.1 Function

The function of the barrier layer is to provide a redundancy in the cover system and divert water if it were to break through the upper cover sections.

### 3.5.2 Life Cycle

The life cycle of the barrier layers includes Stage 1 and Stages 3 and 4. Except for the geosynethic geomembrane that potentially could degrade after Stage 3, the earthen SBL is expected to perform through the life of the cover (i.e., Stage 4). The HDPE geomembrane will continue to perform its intended function until the end of the post-closure stage.

### 3.5.3 Design

The geomembrane and SBL designed for the bottom liner system will function for the cover as well. Consequently, similar analyses used for the bottom liner were applicable for the cover system.

***3.5.3.1 Stress Analysis.*** Stresses will be induced in the cover SBL and geomembrane barrier components due to settlement in the foundation soils waste, and the cover itself. The settlement calculation for the foundation and liner soils is provided in the subsurface consolidation design study (EDF-ER-266). The amount of settlement in the waste and cover itself are provided in the landfill compaction/subsidence study (EDF-ER-267). When the cover settles, the geomembranes will compress, resulting in a reduction in stress. However, the SBL could crack due to excessive settlement. The proposed cover surface will have a slope of 7%. The cover could accommodate an additional settlement (after surface consolidation, cover settlement, and the maximum strains are accounted for) of 13 ft. Approximately 54% (i.e., 6 ft) of the allowable settlement are predicted over the long term. Consequently, the strain in the SBL will not cause cracking and increased permeability.

***3.5.3.2 Puncture Analysis.*** The geomembrane liner will be subject to puncture from the filter layers loaded by overlying materials. A non-woven geotextile will be installed between the geomembrane and filter gravel to provide a cushion. The required puncture resistance of the geotextile was determined based on the analysis performed for the bottom liner system. The round alluvium sand and gravels excavated from the landfill will be screened to remove particles over 2 in. in diameter for the filter layer. The minimum puncture resistance is 124 pounds, including a minimum FS of 2 based on the maximum particle size in the LCRS. The puncture analysis is provided in Appendix B.

***3.5.3.3 Wind Uplift.*** Geomembranes are susceptible to wind uplift, causing damage prior to placing overlying soil layers. The geomembrane in the cover will be anchored with overlying cover materials after the liner system is installed, protecting from wind uplift. However, there will be short periods of time when the geomembranes will be exposed to winds such as during the liner installation. The wind uplift analyses are provided in Appendix C.

***3.5.3.4 Anchor Trench.*** The geomembrane, overlying the SBL, will be terminated in trenches constructed around the perimeter of the cover. The ends of the liners will be buried under 2 ft of earth to protect from wind uplift and pull out. The pull out analysis for the anchor trench is provided in Appendix D.

***3.5.3.5 Settlement Analysis.*** The settlement calculation for the foundation and liner soils is described in the subsurface consolidation design study (EDF-ER-266). The amount of settlement in the waste area cover is described in the landfill compaction/subsidence study (EDF-ER-267).

Landfill covers must maintain a positive slope to promote surface water runoff (Code of Federal Regulations CFR 264.310). The EPA recommends a final top slope between 3 and 5%, after settlement has occurred. The proposed cover surface will have a slope of 7% (EDF-ER-281) and a length of 387 ft measured on its shortest side. Based on the settlement analysis, cover could accommodate additional settlement (i.e., after subsurface consolidation, cover settlement, and the maximum strain are accounted for) of 13 ft. Only 54% of the allowable settlement is predicted, which would result in a cover slope of 4%, which is within the regulatory guidelines.

***3.5.3.6 Freeze-Thaw Analysis.*** SBL can sustain irreversible damage caused by freeze-thaw cycles. Water added during construction for compaction can freeze, increasing the hydraulic permeability through formation of cracks, microcracks, and interconnected macro pores (Benson and Othman 1993). The GCL in the landfill and evaporation pond lining system will be less susceptible to damage caused by freeze-thaw cycles (Krause et al. 1997).

Extreme frost penetration at INEEL is estimated to be 45 in. The ICDF landfill SBL will be protected from frost by 15.5 ft of overlying soil layers in the cover.

***3.5.3.7 Acid Rain Analysis.*** Normal rainfall is typically slightly acidic (pH 5.5) due to the presence of carbon dioxide in the atmosphere. Most acid rain in the United States has a pH of approximately 4.3 (EPA 2002). This pH value is relatively mild and will not have an effect on the ICDF landfill cover SBL.

## 3.6 Filter Layers

The cover will be comprised of two filter-type materials to prevent fine-grained material from migrating to other components of the cover system. The filter layers provide a smooth transition from one material to another. Filter layers also provide capillary breaks due to the contrast in unsaturated permeabilities. Filters are included between the upper soil storage layer and biointrusion, between the biointrusion and SBL, and beneath the side slope armor.

### 3.6.1 Function

Filters allow water to pass while keeping soil particles in place. They are typically comprised of sand and gravel or manufactured from synthetic materials. The filter layers in the landfill cover system will be composed of graded sands and gravels screened from the alluvium material that exists at the INEEL. The gradation of each filter is designed to prevent fine materials from the overlying layer from migrating downward. Filter calculations are presented in Appendix H.

### 3.6.2 Life Cycle

The life cycle of the filter layers includes Stage 1 and Stages 3 and 4. The filter layers will perform their function through the Stage 4 life cycle.

### 3.6.3 Design

Filter criteria calculations were completed to determine the gradational requirements of the sand and gravel filters used to separate fine- and coarse-grained soils. The rock armor and filter design analyses are provided in Appendix H. A summary of rock armor and filter sizes is provided in Tables 3-1 and 3-2, respectively.

Table 3-1. Summary of rock armor sizes.

| | | Percent Finer Than | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Armor/Filter | $D_{50}$[a] (in.) | 12 in. | 8 in. | 6 in. | 4 in. | 3 in. | 2 in. | 1.5 in. |
| Type 1—Side slope armor | 10 – 12 | 100 | 35 – 60 | 15 – 35 | 0 – 5 | | | |
| Type 3—armor biointrusion barrier | 2.5 – 4 | | | 100 | 100 – 40 | 100 – 25 | 30 – 0 | 0 – 1 |

a. $D_{50}$ is the medium diameter of the material.

Table 3-2. Summary of filter sizes.

| | | Percent Finer Than | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Armor/ Filter | $D_{50}$[a] (in.) | 3 in. | 2 in. | 1.5 in. | 3/4 in. | 3/8 in. | #4 | #10 | #20 | #40 | #60 | #100 | #200 |
| Type 2—coarse filter material | 0.15 – 0.5 | 100 | 100 – 85 | 100 – 77 | 86 – 57 | 68 – 42 | 55 – 30 | 40 – 15 | 23 – 0 | 10 – 0 | 3.0 | | |
| Type 1—fine filter material | | | | | | | 100 | 100 – 80 | 90 – 58 | 75 – 43 | 65 – 33 | 55 – 25 | 40 – 12 |

a. $D_{50}$ is the medium diameter of the material.

## 3.7 Vegetation

The landfill cover surface will be seeded and fertilized to promote plant growth. Vegetation will minimize erosion and accelerate removal of water from the water storage layer. Long-term considerations include periods of drought or fire so erosion and hydrologic modeling studies have assumed a poor stand of vegetation. The vegetation will consist of local plant species based on vegetation studies performed for disturbed areas at INEEL (DOE-ID 1989). This should produce a healthier stand of vegetation than natural conditions, providing more transpiration and better erosion control.

### 3.7.1 Function

The function of the vegetation will aid with erosion protection and remove water from the storage layer, increasing upward moisture movement. Since the density of vegetation and the reliability of the existing vegetation in the long term is unsure, it was not relied on entirely to perform any one function.

### 3.7.2 Life Cycle

Vegetation is expected to be present through Stage 4. The Stage 1 life cycle will consist of establishing a good stand of vegetation by application of fertilizers and water as needed. During Stage 3, the vegetation will be maintained and observed so that type of vegetation at the end of the post-closure life will be the best suited for longevity in the INEEL environment. Vegetation during Stage 4 is expected to continue with periods of drought or fire.

### 3.7.3 Design

Vegetation based on native plant species will include:

- Secar Bluebunch Wheatgrass
- Bottlebrush Squirreltail
- Sandberry Bluegrass
- Sodar Streambank Wheatgrass
- Green Rabbit Brush.

The maximum allowable noxious weed percentage (by dry weight) will be 0.5%. The maximum allowable wet and other crop percentage will be 1.5%. The engineered seed mix will provide superior vegetation providing more transpiration and erosion control than the surrounding natural vegetation.

# 4. LINER AND COVER MATERIAL LONG-TERM PERFORMANCE

The long-term performance considerations for the ICDF landfill can be divided into two categories: liner performance and cover performance. The construction quality assurance functions identified in "Construction Quality Assurance Plan for the INEEL CERCLA Disposal Facility" (DOE-ID 2002) will ensure that the regulatory and performance requirements are incorporated during construction; therefore, the largest problem with both of these systems is the potential of liner and cover system degradation over the long-term service life. Material degradation could potentially change the physical properties that would impact the performance of the liner and cover. The soil and rock materials used will not be problematic with respect to degradation if the current materials are specified. These materials have a long track record with respect to degradation based on extensive studies associated with geology. The physical characteristics of geologic materials, such as soil and rock, do change with time, but these changes take a very long time, usually on the order of millions of years.

The ICDF liner and cover system will consist of natural and synthetic materials. A description of each material and its long-term performance characteristics is presented below to determine the viability of the performance requirements being met.

## 4.1 Natural Materials

The majority of the cover and liner systems will consist of the natural materials. These materials will include the following:

- Soil
- Rock
- Vegetation.

The engineering properties of these materials are well understood and have obvious longevity. They will be engineered to perform a specific function in the ICDF such as hydraulic barriers, water storage, transpiration, erosion control, filtration, and drainage. Descriptions of the materials' natural properties (e.g., low permeability, capillary potential, energy dissipation) that make them well suited for their function are provided in the subsections below. Long-term degradation issues are described such as desiccation and freeze-thaw issues in clay soil or erosion potential in rock.

### 4.1.1 Soil Bentonite Liners

SBLs have a natural low saturated permeability due to the clay mineral crystalline structure. Clay is found in abundance in nature as a result of the chemical and physical erosion of rock. Geologically (millions of years), clay will continue to change chemically and physically if exposed to the environment. The clay mineral used in the SBL (e.g., bentonite, montmorillonite) is electrically unbalanced and has an affinity for water. This results in a swelling effect when water is available. Conversely, moisture loss will cause drying and shrinking, which results in cracking. Cracks or desiccation will increase permeability in SBLs. Clays are also subject to freeze-thaw cycles that can increase permeability.

The bottom of landfill will be buried beneath 23 to 38 ft of waste filled to a level surface 2 ft below the crest of the landfill. This provides the SBL used for the ICDF landfill bottom liner with 48 ft to 80 ft of waste soil and cover material depending on the location within the landfill. The SBL used for the landfill cover will be protected by the overlying cover materials 15.5 ft thick. The frost depth at INEEL is approximately 45 in. below the ground surface. Both the SBL in the landfill bottom liner and cover will be below the frost depths. Additionally, at these depths, the SBL will retain its moisture and maintain its low permeability characteristic.

### 4.1.2 Fine-Grained Soils, Sands, and Gravel

Sands and gravel will be used in the cover system for filtration and drainage. There is an abundance of alluvial soils at INEEL that can be engineered to provide the required gradation and drainage properties for each layer in the landfill cover. The alluvium gravels at INEEL are comprised of granite, quartz, and other durable minerals that make it ideally suited for long-term applications.

The upper portion of the cover will be comprised of fine-grained soils that provide good water storage capabilities. These soils are also available at INEEL and have been shown to provide good water storage and release characteristics in engineered barrier studies performed at INEEL. Soil is a product of the decomposition of rock and will retain its properties for the long-term life of the cover. However, its fine-grained composition makes it vulnerable to erosional forces such as wind and water.

The upper portion of the cover will be protected by a soil/pea gravel mulch and vegetation providing an armor against erosion. The cover will also be overbuilt as a contingency in the unlikely event that the soil/pea gravel is eroded, exposing the upper fine-grained water storage material to long-term erosional forces.

### 4.1.3 Rock Armor

Rock armor will line the side slopes of the ICDF landfill. Shallow formations of basalt underlie INEEL and can be easily mined for erosion protection. Basalt is a durable volcanic rock that provides excellent erosion protection, however, it may vary in its density and competency. Los Angeles Abrasion Tests (ASTM C535) will be performed on the rock armor selected for the ICDF cover prior to construction to determine its long-term durability. Based on the results of these tests, rock armor will be oversized if necessary to ensure that it performs its function for the life of the cover system.

## 4.2 Synthetic Materials

The cover and liner system will consist of the polymeric materials listed below:

- HDPE geomembranes and geonets
- Polypropylene geotextiles.

The engineering properties of these materials are well understood and have been used in landfills for containment for several decades. They are manufactured to perform a specific function including hydraulic barriers, erosion control, and drainage. Long-term degradation issues include those listed below:

- Radioactive degradation
- Biological degradation
- Chemical degradation
- Thermal degradation

- Oxidation degradation
- Ultraviolet degradation.

### 4.2.1 Radioactive Degradation

HDPE has a higher resistance to radiation exposure than other liner materials including polyester, polyurethane, and polypropylene (Farnsworth and Hymas 1989). Studies performed on thin films (i.e., 0.002 in.) of different types of HDPE material show that it can become brittle when irradiated at doses between 4,400,000 and 78,000,000 rads. Polymeric material manufacturers reported that it begins loosing its tensile strength and ductility near 1,000,000 rads of total radiation exposure. The normal allowable maximum human exposure is 200 rads for comparison. Samples of HDPE liner exposed to radiation doses up to 37,000,000 rads have a reduction in tensile strength of approximately 25%. Even with the reduction of tensile strength, the geomembrane remains intact and could continue to perform its function as a barrier layer. HDPE geomembranes currently in use today are manufactured with additives to improve ductility and durability such as carbon black and antioxidants. These additives allow higher radiation doses than standard HDPE material alone. The anticipated dose to the primary geomembrane in the ICDF landfill and evaporation pond is 12,000 rads and 100,000 rads, respectively, during their operational life. A complete description of the compatibility of HDPE geomembranes is provided in the liner/leachate compatibility study (EDF-ER-278).

### 4.2.2 Biological Degradation

Biological degradation consists of fungi or bacteria attaching themselves to the polymer, resulting in a change of geomembrane properties. Other types of biological degradation could be from insects or burrowing animals. Tests performed with rats indicate that they were not able to chew their way through geomembranes. Tests performed in the laboratory and in the field show that geomembranes are very resistant to a wide spectrum of biological degradation including manufactured biological additives capable of destroying high-molecular weight polymers like those used in the geomembranes (EPA 1989). Therefore, degradation due to biological attack is very unlikely.

### 4.2.3 Chemical Degradation

That HDPE geomembrane material that will be used to line the ICDF landfill and evaporation pond is considered to be the most chemically inert liner material commercially available. Numerous studies using EPA Method 9090 and permeability tests, among other testing procedures, have been performed for waste disposal facilities and in the laboratory, providing a good understanding of the compatibility behavior of these liner materials. Published studies provide a good tool for establishing compatibility without relying on Method 9090 or permeability testing, which can be time-intensive and require synthetically generating hazardous leachate. A detailed description of the chemical compatibility with the expected leachate composition is described in the liner/leachate compatibility study (EDF-ER-278).

### 4.2.4 Thermal Degradation

Polymeric materials exposed to heat may be subjected to changes in the physical, mechanical, or chemical properties. The amount of change is dependent on the time and severity of exposure. Compatibility and environmental stress rupture tests are performed by submerging geomembrane material in a solution of leachate or surface active agents typically heated to over 120°F. HDPE geomembranes perform very well under these conditions. Most likely, the highest temperatures that the HDPE geomembrane in the ICDF landfill will be subject to occur during construction from exposure to the sun.

After installation, the geomembrane used in the landfill will be buried and remain at a temperature between 50 and 70°F. Thus, thermal degradation will not occur over the long term.

The evaporation pond secondary geomembrane will be protected by a LDRS gravel layer 1-ft thick and a 2-ft-thick operations layer. The primary geomembrane will be protected by a sacrificial geomembrane. However, it will be susceptible to thermal degradation from ambient heat. The sacrificial geomembrane can be monitored during the active and post-closure life so any defects can be quickly mitigated.

Behavior of polymeric materials due to cold temperatures is different when exposed to heat. Cold will not degrade a geomembrane. Geomembranes have been used for landfill and liquid containment systems in the arctic without degradation. Geomembranes behave differently in cold temperatures in that they become stiff and difficult to work with during installation. However, this will not be an issue, as construction will be completed over the summer.

### 4.2.5 Oxidation Degradation

Oxidation degradation results in a loss of mechanical properties and ductility of the geomembrane. Oxidation can occur when exposed to high temperatures (i.e., 200°F). Oxidation degradation can also occur when the geomembrane is exposed to the sun for long periods of time. Burying geomembranes under soil minimizes geomembrane contact with oxygen and significantly reduces or eliminates oxidation degradation. Geomembrane manufacturers also add antioxidant agents in the geomembrane to reduce the potential for oxidation degradation. The primary geomembrane will be protected from oxidation degradation by the sacrificial geomembrane. The sacrificial geomembrane will be monitored and repaired or replaced as necessary during the life of the evaporation pond.

### 4.2.6 Ultraviolet Degradation

Polymers degrade when exposed to ultraviolet light due to photo oxidation. Additives in the geomembranes such as carbon black are used to retard ultraviolet degradation. The sacrificial geomembrane in the evaporation pond will cover the primary geomembrane, protecting it from ultraviolet degradation. The geomembrane in the landfill will be covered by soil, eliminating ultraviolet degradation.

As long as antioxidants are present in the geomembrane, the physical and mechanical properties of the geomembrane can be preserved. Accelerated aging studies have been performed on HDPE geomembranes to estimate the length of time it requires to deplete the antioxidants in geomembranes. The results of the study indicate that 80 years at an ambient temperature of 68°F would be required to deplete the antioxidants in an HDPE geomembrane (Hsuan and Guan 1998). Other factors such as freeze-thaw, ultraviolet degradation, high temperature, and normal wearing due to cleaning may significantly reduce serviceable life. Conceivably, the sacrificial geomembrane could remain functional for its expected 45-year service life.

# 5. OTHER LONG-TERM ISSUES

## 5.1 Human Intrusion

To deter the inadvertent intrusion of humans into the waste, a marker system will be used to warn future generations of the dangers of the buried waste. DOE intends to maintain active control of INEEL (using fences, patrols, alarms, and monitoring instruments) for the foreseeable future. If these measures should cease, other passive-type measures will warn the inadvertent intruder from waste buried beneath the permanent cover barrier. The measures may include recognizable warning markers and other physical features. Site information will be provided on an Internet website, U.S. Geological Survey maps, libraries, and other information repositories that would be readily available to the public.

The ICDF landfill will have a steep rocky side slope of basalt riprap. This feature clearly delineates the boundaries of the surface barrier by providing a distinct contrast with the surrounding flat terrain. These side slopes are engineered structures that will be obvious that the structure had been built by humans. These distinct riprap side slopes in combination with warning signs will minimize the risk of human intrusion.

## 5.2 Potentially Disruptive Natural Events

Potential disruptive events would include a high wind condition, earthquake, or massive flood event. The likelihood and magnitude of these events at the INEEL are discussed in the following paragraphs. How the cover would be affected by these catastrophic events is also discussed.

Tornado-type winds are expected to be extremely rare at the ICDF Complex. The side slope armor will consist of large heavy basalt riprap that will resist tornado-type winds. The surface of the permanent cover will consist of vegetation and soil/pea gravel matrix. The soil/pea gravel matrix has shown to be resistant to high wind forces generated in wind tunnel tests performed at the Hanford facility.

A static and pseudo-static slope stability analysis was performed for the cover system. A seismic event was simulated in the analyses by using the peak bedrock acceleration that would occur from an earthquake event having a one in 10,000-year return period. The estimated resulting seismic loading mode, and magnitude, would not create a FS of less than one. The ICDF Complex is situated outside the Big Lost River 100-year floodplain. A wide band of Quaternary alluvium extends along the course of the Big Lost River from the southwestern corner of the INEEL to the Big Lost River sinks and playas in the north-central portion of the INEEL. Rathburn (1991) maps and describes the Big Lost River alluvium throughout the drainage and relates the deposition of those sediments to paleoflooding of the Big Lost River. At the location of the Idaho Nuclear Technology and Engineering Center and ICDF, the surficial alluvium is mapped and described as "gravel armored silt deposits, forming laterally extensive planar surface." The dominant grain size within these deposits is predominately gravel in a sand and silt matrix with some small cobbles. The deposits typically display horizontal and trough cross-bedding. The mode of deposition for these sediments is inferred as flood delta or fans related to cataclysmic paleoflooding events that occurred during the last glacial period. The age of these deposits is late Pleistocene and they are likely deposited in association with the Pinedale Glaciation of approximately 30,000 years before present. Rathburn further states that in general these paleoflood deposits rest approximately 15 to 20 ft above the modern Big Lost River, exhibiting a topographic reversal, or the situation where older deposits are topographically higher than the younger deposits. The lateral continuity and generally unaltered morphology of the paleoflood deposits show that few, if any, subsequent stream flows were able to overtop and disrupt these paleoflood deposits.

The ICDF Complex is situated outside the 100-year and 500-year Big Lost River floodplains predicted by the United States Geological Survey (Berenbrock and Kjelstrom 1998) and United States Bureau of Reclamation (DOE 1999b), respectively. As a conservative check, the ICDF landfill was analyzed for the effect of the 500-year flood event flowing past the side slopes described in Section 3.1.3.2. Floodwaters at the base of the cover were assumed to rise to an elevation of 4925 or 4 ft below the crest of the landfill berm. At this level, the estimated flow velocity is approximately 2.5 ft per second. Even during active landfill operations, this flow velocity and potential erosion can be resisted using native vegetation on the slopes.

The United States Geological Survey study predicts the 100-year flood event to reach an elevation of 4917 feet or 12 ft below the crest of the landfill berm and the Bureau of Reclamation 500-year flood event is predicted to reach an elevation of 4915. These different studies use different analytical solutions and different assumptions in determining the flood levels. If these massive flood events overtopped the banks of the Big Lost River and flowed past the ICDF landfill, floodwaters would be below the landfill crest and would not erode the side slope rock armor. Beyond the geological deposits left by the Big Lost River system, there is no evidence that a large precipitation event would cause massive flooding of the magnitude necessary to erode the permanent ICDF side slope rock armor.

Cover Performance Beyond 1,000 Years

Although the permanent ICDF cover barrier has a design life of 1,000 years, it could conceivably perform beyond this time. Its earthen material composition allows the permanent cover to perform like a geological structure requiring many years to break down its outer shell of rock armor. Forces of a catastrophic nature would be required to compromise the 17.5-ft cover comprised of soil, gravels, rock, and clay. Consequently, there is a likely probability that the cover will continue to perform after its 1,000-year design life.

# 6. CONCLUSION

This long-term performance study and life cycle analysis demonstrates that the ICDF landfill and evaporation pond designs meet all ARARs, which include the substantive requirements of 40 CFR 264, IDAPA, DOE O 435.1, the ROD, and EPA Guidance Documents. A detailed final cover design was provided and demonstrates that the cover will serve as an effective intrusion barrier and minimize infiltration for at least 1,000 years and conceivably beyond this time.

For each design analysis, the associated ARARs and performance design criteria were defined, and the appropriate calculation completed. Unless otherwise referenced from other ICDF design studies, the completed calculations are provided in the Appendices attached to this report. This study also included an explanation of how the design analyses consider the required liner and cover service life. Explanations have been provided to demonstrate how the cover system will meet the design life of 1,000 years and the regulatory and performance requirements. It should be noted that the cover system described in this study applies only to the ICDF landfill. Additional information will be provided in the Remedial Action Work Plan regarding the anticipated closure alternatives for the evaporation pond. This study also included the complete design analysis for the landfill cover and liner system, and identifies the long-term considerations from material selection through operation of the ICDF landfill. Based on the results of the study, the cover will meet the long-term performance requirements and the expected design life.

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