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FINAL CLOSURE COVER FOR A HANFORD RADIOACTIVE
MIXED WASTE DISPOSAL FACILITY

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Final Closure Cover for a Hanford Radioactive Mixed Waste Disposal Facility

KD Johnson

Westinghouse Hanford, Richland, WA 99352

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Abstract: This study provides a preliminary design for a RCRA mixed waste landfill final closure cover. The cover design was developed by a senior class design team from Seattle University. The design incorporates a layered design of indigenous soils and geosynthetics in a layered system to meet final closure cover requirements for a landfill as imposed by the Washington Administrative Code WAC-173-303 implementation of the Resource Conservation and recovery Act.

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**FINAL CLOSURE COVER FOR A HANFORD
RADIOACTIVE MIXED WASTE DISPOSAL
FACILITY**

**PROJECT REPORT
TO:**

**WESTINGHOUSE HANFORD CORPORATION
JUNE 3, 1994**

**ENGINEERING DESIGN CENTER
SCHOOL OF SCIENCE AND ENGINEERING
SEATTLE UNIVERSITY**

Westinghouse Hanford Environmen-
tally Compliant Final Closure Cover
Seattle University Design Project
Design Team CEE 94.6
Broadway and Madison
Seattle, WA 98122
Phone:(206)296-5525

June 3, 1994

Attention: Dallas A. Hoover
Westinghouse Hanford Comp., MS/N3-13
P.O. Box 1970, Richland, WA 99352
Phone:(206) 296-5503

Westinghouse Hanford Company,

Re: Final Project Report for a Permanent Cover on a Low-Level Mixed
Radioactive Disposal Site (W-025) Located in the 200 West Area at Hanford.

The enclosed Final Project Report is in response to the tasks given to Seattle University's
Design Team CEE 94.6, by the Westinghouse Hanford Company.

The recommended design incorporates a combination of geosynthetics and indigenous
soils in a layered system cover which meets or exceeds the Resource Conservation and
Recovery Act(RCRA), the State of Washington, and The Department of Ecology
regulations to gain permit for operation of a Hazardous Waste Disposal Facility. The
combination of geosynthetics and natural soils prevent gas accumulation, surface water
infiltration, and will be erosion resistant while minimizing long-term maintenance
requirements.

Working with the Westinghouse Corporation has been enjoyable and challenging. Thank
you for sponsoring our design project, the experience gained has been invaluable.

Respectfully Yours,

Jeffrey E. Dye
Staff Engineer
Design Team CEE 94.6

Mark A. Stockton
Staff Engineer

Steven P. Nicholas
Staff Engineer

**DESIGN OF AN ENVIRONMENTALLY COMPLIANT
FINAL CLOSURE COVER FOR THE HANFORD
RADIOACTIVE MIXED WASTE DISPOSAL FACILITY**

PROJECT REPORT TO: WESTINGHOUSE HANFORD COMPANY

CONDUCTED BY: SEATTLE UNIVERSITY DESIGN TEAM -
CEE 94.6 - JUNE 3, 1994

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EXECUTIVE SUMMARY

Westinghouse Hanford Company located at Hanford, Washington, is currently using burial grounds to store mixed radioactive waste by-products. The systems used to ensure final closure for these burial grounds incorporate both, a liner system and a cap cover design which form the leachate and water infiltration barriers for the burial ground. Because of the Resource Conservation and Recovery Act (RCRA) and The Washington State Department of Energy (DOE) regulations, a project was undertaken to determine if a design for an environmentally compliant cap cover could be finished while meeting these regulations. This research project will provide Westinghouse Hanford Company with vital information toward their future cover designs.

ABSTRACT

The W-025 landfill cap cover was designed specifically for the Westinghouse Hanford Company by Seattle University Design Team CEE 94.6. The cap cover design incorporates a layering system using both geosynthetic products and indigenous soils. The landfill itself will be filled with low level mixed radioactive waste. For this reason great care was taken to ensure that erosion, settling, gas percolation, and transportation of migrating rain water and potential leachates would be controlled with minimum maintenance. This ensures the lowest cost. The design meets or exceeds all of the regulations set forth by The Resource Conservation and Recovery Act (RCRA) and The Washington State Department of Energy (DOE). The design also meets additional requirements set forth by Westinghouse.

ACKNOWLEDGMENTS

Design Team CEE 94.6 would like to give special thanks to all those who volunteered help during our design process. Without their help and guidance we would have found it very difficult to complete the our given tasks.

Dr. Rolf T. Skrinde, Faculty Advisor and Head of The Engineering Design Center

Frank Shurri, Project Engineer, Golder Associate Inc.

Kevin Johnson, Project Engineer, Westinghouse Corporation, Hanford

Dr. Arthur Benedict, Professor, Seattle University

Dr. Nirmala Gnanapragasm, Professor, Seattle University

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INTRODUCTION

The project design presented herein was carried out for the Westinghouse Hanford Company(WHC), a subsidiary of the Westinghouse Electric Corporation. WHC is the Operations and Engineering Contractor for the Hanford Site and is leading the cleanup and environmental restoration of the Site under the Tri-Party agreement between the Environmental Protection Agency, State of Washington and Department of Energy(DOE).

Statement of the Problem:

A Hanford Radioactive Mixed Waste Disposal Facility was constructed in the 200 West Area of the Hanford Site. Prior to obtaining an operators permit from the State of Washington, a Closure Plan for the facility must be prepared and approved by the Washington State Department of Ecology. The Environmentally Compliant Closure Plan must include a description of the proposed final closure cover for the disposal facility which will meet or exceed all applicable State and Federal Laws and Regulations. The objective of this project was to prepare an engineering design of the final closure cover.

Background:

Established in 1943, Hanford is a 560 square mile installation of the U.S. government, managed by the Department of Energy-Richland Operations Office. The site is located near Richland in southeastern Washington State as shown in Figure 1. Currently, Hanford employs a work force of approximately 13,000 scientists, engineers, managers and support specialists. The Hanford Site is the Department of Energy's second oldest nuclear facility. Figures from 1990 indicate that Hanford Facilities have a value of \$8.5 billion, with an annual budget of approximately \$975 million.

Originally, nine water-cooled, graphite-moderated plutonium production reactors were constructed along the Columbia River by the U.S. government between the years 1943 and 1963. These facilities were reactor and chemical separation facilities for production and purification of plutonium for possible use in nuclear weapons. All of these reactors are now retired from service with only one remaining on standby for the production of plutonium and for the production of steam to generate electricity.

The Hanford Site is large, approximately one half the size of Rhode Island. This background information deals primarily with the 200 West Area, which includes Trench W-025, for which the closure cover design is prepared. Figure 2 shows existing and future locations of burial sites located at the 200 East and 200 West Areas within the Hanford Site. The 200 areas are located near the center of the Site, about 6.8 miles from the Columbia River, on a large bar of sand and gravel. known as the "200 Area Plateau". Facilities and sites existed in the 200 Areas for nuclear fuel processing, plutonium separation, plutonium fabrication, high-level and transuranic radioactive waste handling and storage, low-level radioactive waste handling and disposal, and hazardous mixed

FIGURE 1 - DOE'S HANFORD SITE, WASHINGTON STATE

HANFORD SITE

Department of Energy

FIGURE 2 - 200 WEST AREA LOCATED IN NORTH CENTRAL HANFORD SITE

waste. The trench to be covered, is approximately 300 ft. by 450 ft. in dimensions and is known as the W-025. Golder Associates of Redmond designed the trench which is presently under final inspection for specification compliance. The above-mentioned trench is located in the 200-West Area as shown in Figure 3.

The environment and physical characteristics provide a basis for satisfying the requirements in designing the final closure cover for these trenches. This project dealt with one specific cover in the 200 West Area but its design may represent the desired cover for other trenches at Hanford. For this reason, the environmental characteristics or parameters affecting the final closure cover design are discussed in detail. This, however, created an extensive section which will be implemented as Appendix A in this report and in the Final Report to the Westinghouse Hanford Company. Also, major historic events for the Hanford Site are shown as a complete Hanford History Time-line in Appendix B.

Under current requirements, a closure plan must be implemented due to past procedures that are stated below. In the past, radioactive and mixed solid waste has been disposed of in shallow trenches and covered with eight feet of earthen cover material. These covers are interim until the trenches were filled and a final closure was designed and implemented following the Final Closure project. The waste comes from Hanford itself, however, some outside Companies are permitted to dispose of inactive radioactive hazardous waste at Hanford. There are approximately 500 acres of trenches at the Hanford Site.

Currently, Hanford has been in the public eye more than at its origination, its cleanup is being driven and supported by increasing environmental concerns. Plans and agreements which are driving environmental cleanup and closure plans are the Hanford Environmental Management Plan, and the Environmental Compliance and Tri-Party Agreement Implementation. They are described below but in much greater detail in Appendix A.

Environmental protection and improvements are major Hanford initiatives. The "Hanford Environmental Management Plan" provides for a comprehensive environmental surveillance and compliance program to monitor and assess the impact of operations on the Site and regional environment.

The "Environmental Compliance and Tri-Party Agreement Implementation" is a legally-binding agreement between the U.S. Department of Energy-Richland Operations Office, the Washington Department of Ecology(Ecology), and the U.S. Environmental Protection Agency(EPA). Signed May 15, 1989, the agreement's purpose was to facilitate Hanford Site compliance with Response, Compensation, and Liability Act(CERCLA, Superfund), and Washington State Hazardous Waste Management Act(HWMA) requirements.

FIGURE 3 - TOPOGRAPHY OF WASTE MANAGEMENT AREAS 3 AND 4, TRENCH W-025 IS ALSO SHOWN

The RCRA regulations do not specify a particular design for covers of low level hazardous waste, rather they specify the performance criteria to be met. The final cover of the waste disposal cell must provide long-term minimization of liquid migration, function with minimum maintenance, promote drainage and minimize erosion or abrasion to the cover, accommodate settling and subsidence which assures cover integrity, and must have a permeability less than or equal to the permeability of any bottom layer system.

The Closure Cover was considered in three phases: 1) Design, 2) Construction, and 3) Maintenance. Final Closure Cover design considerations included: types of waste to be stored, minimum 30 year life span, construction costs, maintenance(i.e. stability of materials/erosion), percolation, weather patterns(i.e. runoff, freezing, annual precipitation, wind), and settlement or subsidence. Contaminated wastes or low-level radioactive/hazardous waste, to be placed in the disposal cell were primarily inorganic materials that include raffinate, contaminated soils and sediment, and debris. The wastes were placed to minimize differential settlement, reduce Radon exhalation, and control the upward migration of contaminants by capillary action.

Functions of the top cover and side slopes were to minimize moisture infiltration into the contaminated materials in the cell and to reduce exhalation of radon gas from contaminated materials. Cover Soil stratification resembled that of a highway pavement system. The layered system included a vegetative chock rock layer at least 6 inches thick; a rip-rap layer 1 foot thick; a filter layer; and the continuation of the top cover radon barrier.

Due to the main intent of this project report, a more detailed background can be obtained from the Project Proposal delivered to Hanford in December of 1993.

Purpose of Project:

The purpose of this project was to design an Environmentally Compliant Final Closure Cover for a Hanford Low-Level Radioactive Mixed Waste Facility at the W-025 trench site. Specifically, this closure plan must be approved by the State of Washington and the Federal Environmental Regulations prior to obtaining an operator's permit allowing Radioactive Waste burial in the W-025 trench, which is located in the 200 West Area of the Hanford Site.

METHODS AND DESIGN APPROACH:

Plan of Implementation

The proposed Plan of Implementation was a logical process to analyze how the different Closure Cover Designs generally compare to each other. This Final Report contains detailed criteria and an assessment process used in evaluating Alternative Cover Designs(i.e. Cost/Benefit comparison) to ultimately determine the preferred alternative cover design.

Both the *Primary and Secondary Cover Designs* presented in this final report for the final closure cover meet or exceed the regulations set forth by the Environmental Protection Agency (EPA), Nuclear Regulatory Commission (NRC), State of Washington, Department of Energy (DOE) and the Resource Conservation and Recovery Act (RCRA) with regard to storage of low level nuclear waste.

At final closure, the proposed final covers,(per criteria set forth by RCRA, DOE, and Hanford) provide long-term minimization of liquid migration and function with minimized maintenance by promoting proper drainage and erosion control on and around the cover. A guarantee of a 30 year life span to Westinghouse is possible, though manufacture's guarantee on the life span of synthetic materials used in both the Primary and Secondary designs is but twenty to twenty-five years. Currently, the synthetic materials are questionable due to the limitation of the manufacture guarantee on life span of synthetic materials used in cover designs. The synthetic materials will be exposed to UV rays for only a short period and once buried, oxygen and moisture contents will be negligible. It is therefore reasonable to assume that with the above conditions, the synthetic materials expected life span may be extended additional ten years.

Due to the political sensitivity of Hanford, request for site specific soil samples were unattainable making soil analysis difficult. Without this data, calculations involving soil characteristics seemed an effort in futility. A decision to seek soil data attained from outside sources was determined to be the only alternative left for a successful design. The most logical source of up to date information regarding the W-025 site was Golder Associates, designers of the disposal trench liner system. Using the resources of Seattle University's Design Center, contact with Frank Shurri, Project Manager for the Hanford W-025 Trench Project of Golder Associates was made in February of 1994. A good rapport with Mr. Shurri developed and with his approval, the necessary soil data needed to complete the design project was provided. All design calculations in this final report are based on soil tests performed by Golder Associates in 1989 (REF GOLDER CONSTRUCTION REPORT, 1994).

Golder Associates of Redmond assisted our team by providing answers to questions pertaining to:

- Permeability of existing soil, hydraulic conductivity of bottom liner.
- Slope-stability, and shear integrity of the existing soil.
- General questions about Hanford.

Using the criteria set forth in the Plan of Implementation, five cover designs were considered (Proposal of Final Cover Design to Westinghouse by Design Team 94.6, Seattle University, 1993). All were reviewed and none, as drawn, would totally satisfy the criteria requirements. Cover or liner systems recommended by federal and state regulations required a system with two impermeable layers.

Research indicated the top soil layer required sufficient depth to accommodate protection from burrowing animals; deep rooted plants indigenous to arid regions; a 25 year, 24 hour storm event; and withstand erosion by wind and water. None of the proposed alternatives provided an adequate solution to the entire problem. To protect the surface area from wind and water erosion, planting indigenous grasses and small, low growing brush, such as, sagebrush, rabbit-brush, cheatgrass and Sandberg bluegrass is strongly recommended. Obtaining local manure and mixing it with local soils would add nutrients and encourage plant growth.

Soil depth was increased to 2.5 feet from the initial depth of 2.0 feet to increase the soil volume in order to accommodate the calculated worse case scenario of 1.56 inches per hour (Ref Design Report, Golder Associates, 1991). The primary function of the top soil layer was to absorb water and release it back to the atmosphere through evaporation.

Borrowing the concept of a 1.0 foot rip-rap layer and incorporating a tough, synthetic woven material above the rock layer, this acted as a secondary protection barrier to infiltration by animal and plants. Additionally, the vent system incorporated a stainless steel screen to keep animals from entering the vent(See Figure 4 and Figure 5). Secondly, the rock layer acts as a low resistance pathway that channels infiltrated water to the two synthetic layers below; the geonet and high-density polyethylene (HDPE) (See Figure 5). To ensure integrity of the cover's surface, side slopes are not to exceed a 3H:1V, (3 horizontal and 1 vertical), incline. Also it is suggested that a slope of 3 to 5 percent will be sufficient to promote run-off without risk of excessive erosion.

The drainage layer consists of a geonet, a synthetic material designed to filter and channelize water flow in conjunction with the impermeable HDPE liner. Decision to incorporate the use of the geonet instead of a sand layer was based on two factors. One, no subsidence occurs with the geonet, thus reducing the probability of cover subsidence and second, overall construction cost reduction(Shipping and placement costs for sand installation are the determining factors). An HDPE liner of 40 mil is the minimum requirement by DOE and RCRA regulations. To ensure side slope stability and integrity of the entire cover, selection of a textured, 60 mil was recommended. The combination of the fabric sided geonet and textured HDPE acts similar to velcro and was extremely stable. Precipitation run-off is channeled to an open trench system and infiltrating moisture is collected by a 6 inch perforated pipe. As mentioned above, to comply with federal and state regulations, a double liner system was required. The HDPE satisfied one liner requirement and the suggested compacted admix layer satisfies the second liner requirement.

Test data collected by Golder Associates regarding shear tests of the compacted layers with different percentages of added bentonite was analyzed. Results indicate that a 12%

PASSIVE VENTING SYSTEM

FIGURE 4 - GAS COLLECTING AND VENTING SYSTEM IN GRAVEL TRENCHES
ABOVE WASTE CELL

STRATIFICATION OF FINAL COVER

FIGURE 5 - STRATIFICATION OF FINAL COVER (PRIMARY DESIGN)

mixture of bentonite and soils from either the W-025 site or the two borrow sites yields the most favorable results (ref. Design Report, Golder Associates, 1993). Recent site testing performed by Hanford of the trench liner system indicates a hydraulic conductivity of 10^{-8} cm per second. These hydraulic conductivity results suggest that the native soil and 12 percent bentonite mixture will accommodate the precipitation generated by a 25 year, 24 hour storm event. Lastly, the admix layer acts as a smooth and stable foundation for the HDPE liner.

As mentioned at the beginning of the methods and design approach section, a Primary and Secondary Cover Design was submitted. The difference between the two designs is the compacted admix layer which was substituted in the Secondary Cover Design with a geosynthetic clay liner(GCL). To provide a smooth and stable foundation for the membrane, a one foot layer of soils obtained from the McGee Ranch is recommended compacted to a 95% Proctor. This surface, regardless of cover selection, is to be free of debris, roots and angular or sharp rocks. The cost of the Admix preparation and shipping of the bentonite clay will be offset by the installation of this GCL.

In summary, the cover configuration was primarily determined by federal and state regulation. Integrity and ultimate life-span of the cover was greatly influenced by the limitations of the manufacture's warranties, the environment and the subsidence that may occur in the waste cells. Of the above three, subsidence is the least concern provided a high rate of compaction is maintained during the backfilling procedure of the waste cells. Golder Associates estimated a total subsidence of less than 6 inches within their liner system (Design Report, Golder Associates, 1993). Subsidence within the waste cell will be determined by the deterioration waste rate, consolidation and compaction rate. Some subsidence is expected over the life-span of the final cover and scheduled maintenance is recommended depending on frequency of subsidence. Exterior configuration and open trench design will accommodate light weighted, rubber tire machinery, such as, a backhoe or tractor with a front loading bucket for use on the cover's surface for maintenance purposes.

Consideration of escaping radon gas will be addressed by a venting system as shown in Figure 4, but is expected to be a minor concern. The venting system will include two vertical vents for the cover. Most radon gas will remain in leachate controlled by the bottom liner system.

To minimize the infiltration and percolation of water through the cover, special attention to soil selection, blending of soils, and compaction and layering must be considered during design and construction. Fine-grained soils with inherently low permeability("k") values were the preferred materials being considered. However, if well-graded fine soil are not available but coarse and fine grained soils are, blending will be considered as an alternative means to impede the passage of water into the solid waste cells.

Layering and compacting different soils into horizontal stratification, as shown in Figure 5, will be recommended to comply with RCRA and DOE regulations. The importance of soil

compaction can not be over-emphasized as a cost effective means in reducing infiltration and percolation. This results in decreasing the porosity of the soil and thus sharply reducing the k values. Proper compaction also decreased discontinuities in the cover thus limiting depression or subsidence which cause ponding of water.

An impermeable membrane and gas barriers were also specified by federal and state regulations at hazardous waste sites to be incorporated in the layering system to thereby stop percolation of water into the cell. Because of the high cost of these cover systems, several manufacturers and their products were scrutinized to determine which system best meets the criteria of the Hanford Site's Final Cover Plan.

Materials to be used in the cover configuration were investigated to determine the cost and availability of preferred materials that meet the required RCRA regulations.

Gases produced in waste cells may move through cover layers and surrounding soil to the atmosphere or adjacent substrata. Flow can take place either by diffusion or in response to a gradient of total pressure. The total pressure gradient mechanism is usually subordinate in solid waste except in those cases where it is feasible to pump gases into or from waste cells. Flow of gases is dependent on several physical parameters, particularly porosity, degree of saturation and free space gas diffusivity.

To minimize gas movement, an attempt was made to use the finest grained soil available in adequate quantity for best results in the final cover. A sand or gravel is the preferred soil for facilitating gas flow. If sand or gravel prove to be cost prohibitive or unavailable, decreasing porosity of the soil by appropriate compactive efforts was a desirable means to reduce gas migration. To meet the required federal and state regulations, a combination of compacted fine grained soil and an impermeable membrane are to be implemented into the final cover.

Gas production has been predicted by Westinghouse to be negligible, however, to ensure the integrity of the cover by eliminating the possibility of a "ballooning effect" of the HDPE liner, it is recommended that the enclosed passive gas venting system be incorporated into the Final Cover Design. See Figure 4 which displays a simple design for venting gases.

Suggested exterior design configurations of the final cover were divided into two categories of top surface and side surface. Maintaining the cover's shape and integrity will depend upon two factors; water and wind erosion control. Of the two, water erosion was the primary concern. Climate data of the Hanford site indicates rainfall averages 6.3 inches of precipitation per year; most of which is in the form of snow. Winds primarily are

from the Northwest not exceeding 10 mph through out the year. The 100 year extreme maximum wind is estimated to be 85 mph. See Figure 6.

Rainfall run-off increased with an increasing slope of the surface; hence, infiltration decreased. Since erosion also increased with an increasing slope, the design of the surface slope should balance opposing considerations where percolation is undesirable. Past observations showed that for slopes of less than 3%, the irregularities of the surface and vegetation commonly acted as traps for detention of run-off (Reference Figure 6). It is suggested that a slope of 3 to 5 percent will be sufficient to promote run-off without risking excessive erosion.

Stability of the cover's side slope was critical because the slope will confine potentially harmful waste. Any failure of the side cover may release contaminants directly into the environment. Design for stable slopes incorporated features for controlling subsurface drainage and developing adequate shear strength. If materials available at the Hanford site were inferior soils, it may be necessary to adjust the design to include one of three basic configurations used for side or sloping cover at solid waste disposal areas.

To determine the selection of soils available for embankments, it was advised that further testing for shear strength be performed on available soils. Allowances should also be made for the compaction and corresponding strengthening effect. Regardless of the soils selected, side slope surfaces were not to exceed a 1:1 slope (Reference Figure 7). Decreasing the design inclination is directly effective in increasing stability of soil slope and erosion control. Allowance for freeze/thaw have been considered in the final cover design. However, this proved to be a secondary concern because the average temperatures in the winter at Hanford are 35.6 degrees Fahrenheit. The freezing effect does create reduced permeability in the soil. Gravel and sands are the best materials for resisting frost heave but are less stable on slopes therefore a coarse-grained soil was recommended for the top soil layer

Wind erosion control can be effectively maintained by an indigenous vegetation cover. Dominant plants on the Hanford site are large sagebrush, rabbit-brush, cheatgrass, and Sandberg bluegrass. The importance of vegetation in reducing wind erosion cannot be overemphasized. The effectiveness of vegetation in reducing wind erosion is increased when the growth is erect and tall. Vegetation also decreases water erosion and helps absorb precipitation thus decreasing water infiltration.

FIGURE 6 - CONCEPTUAL COVER DESIGN FOR HANFORD RADIOACTIVE MIXED WASTE DISPOSAL FACILITY

HANFORD RADIOACTIVE
MIXED WASTE DISPOSAL
FACILITY
CONCEPTUAL COVER DESIGN AND
COVER SECTIONS
DRAWN BY DESIGN TEAM 94.6 - 9/4/94

PASSIVE DRAINAGE SYSTEM

WHC-SD-WM-ES-357, Rev.0

FIGURE 7 - PASSIVE DRAINAGE SYSTEM - CONFIGURATION AT SLOPING
SIDES OF DISPOSAL AREA

In summary, the interior design configuration was primarily determined by Federal and State regulations, however, life-span of the facility is indicated to be at least 30 years(Referenced by Golder Associates Inc.. Redmond, WA). This fact and the availability of preferred materials will greatly influence the final design and construction process.

Regardless of the cover's indicated life-span, basic requirements must be met to satisfy RCRA and DOE regulations. The final cover must provide long term minimization of water migration and is predicted to function with minimal maintenance. This was accomplished by an interior design consisting of a layer system of varying thicknesses incorporating fine-grained soils with low permeability or blended compacted soils, on-site rip-rap gravel and an impermeable geosynthetic membrane. The final cover is to have a permeability less than or equal to the permeability of any bottom liner system. To minimize gas movement, a passive venting system is recommended.

Exterior configuration was divided into two categories of a top surface and side slope surface. Slope of top surface was to fall within a range of 3 to 5 percent. Design of side slopes was dependent upon shear strength testing of available materials. Options of three configurations were considered to maximize slope stability. To minimize maintenance, proper drainage, water and wind erosion were of high priority and therefore the design will reflect these concerns.

Criteria for Assessing Cover Design and Material Alternatives

The analyzed designs for the final closure cover must meet or exceed the regulations set forth by the Environmental Protection Agency (EPA), Nuclear Regulatory Commission (NRC), State of Washington, Department of Energy (DOE) and the Resource Conservation and Recovery Act (RCRA) with regard to storage of low-level nuclear waste. Our proposed cover design will satisfy all environmental regulations or requirements. Other criteria is shown in Appendix C and D to this report.

Selection Criteria for Synthetic Liner Alternatives

Various companies were contacted regarding layer/membrane liner information. These companies supply the following:

o Geosynthetic Clay Liners(GCLs):	3 Companies.
o High Density Polyethylene (HDPE) Membranes	6 Companies.
o Woven and Nonwoven Geotextiles.	2 Companies.
o Bentonite for Compacted Clay Liners	1 Companies.

Companies names and general locations are included below:

- o CETCO (Illinois) Geosynthetic Clay Liner(GCL)
- o James Clem Corp.(Georgia)- Claymax Geosynthetic Clay Liner(GCL)
- o FSI, FLuid Systems, Inc. Bentofix Geosynthetic Clay Liner(GCL)
- o Seaman Corp.(Bellevue, WA) - Permalon High Density PE Membranes
- o SLT N. America (TX), HDPE Geomembrane used by Golder Associates
- o POLY-FLEX High Density PE Membranes, HDPE (Texas)
- o National Seal Company HDPE, VLDPE or CoexSeal(coextruded geomembrane, textured friction seal)
- o Gundle Lining Systems, Polyethylene Backing
- o Stevens Geomembranes, Polypropylene (MA)
- o Trevira Spubond Geotextile (Bellevue Rep)
- o Synthetic Industries (TN, Kent), Woven/Nonwoven Geotextiles.
- o Maccaferri Gabions, INC(Redmond, WA)- Gabions, Retaining walls for toe drain or erosion control.
- o Presto Products Co.; GEOWEB Cellular Confinement System(Honeycomb), to confine cohesionless soils, sand, gravel
- o Black Hill's Bentonite Company, Wyoming Bentonite Supplier for the admix layer

Major Considerations for determining the best liners or membranes for the cover design included the following:

Climate, settlement, cover erosion/puncture vulnerability, allowable percolation, gas collection, slope incline stability, existing soil properties(i.e. shear) effecting liner/soil interface stability.

Specific criteria may include:

- o Total Cost of material, installation and shipping.
- o Availability of products or materials. (i.e. soil vs bentonite)
- o Product functionality advantages. (i.e. costs, permeability advantages)
- o Product functionality disadvantages(i.e. Clay layer may crack, weather, dessicate)
- o Cover Design Characteristics. (i.e. Slope, layering alternatives)

As mentioned before, criteria was first selected for determining the best liner or combination liner system which was developed by research and general cover construction and adherence to environmental factors. A "Decision Matrix" on the various liners was then developed to begin the limiting process to assess the best liner or combination of liners. One large Decision Matrix was broken up into 3 decision matrices since the different liners served several purposes. These matrixes are at the start of Appendix C. The three decision matrixes were broken up as follows:

Matrix #1:

- o Woven and Nonwoven Geotextiles (WG or NWG, respectively).

Matrix #2:

- o High Density Polyethylene (HDPE) Membranes, (GMs = Geomembranes)

Matrix #3:

- o Geosynthetic Clay Liners(GCLs):
- o Compacted Clay Liners (CCLs) *Not recommended by itself or exposed, can be used in a composite liner layer system or as in an admix layer like in this project's design.

Regulatory requirements for Hazardous Waste Disposal prompted a least a two liner barrier. An independent study for general landfill covers revealed that a combination of an HDPE geomembrane with a compacted clay liner (CCL) was not as good a barrier as an HDPE and a Geosynthetic Clay Liner (GCL). The benefits and costs were used to determine this. (Reference Figure 8, a table from Civil Engineering Magazine "Better Cover Ups", Page 55, May 1992.) The CCL has had widespread use in the U.S. as a liner, but its long term performance as a barrier may have many problems when it is used in a pure state. These problems included difficulty to compact properly on soft foundations, tended to desiccate from above and below unless adequately protected, vulnerable to damage from freezing, differential settlement will cause tensile strains or cracking, and these liners are difficult to repair if they crack.

Our Primary Design uses a 12% ratio of Bentonite clay in an Admix layer. This optimized the major advantages of this material since it was used as an additive. The remaining liner will serve as protection against the above mentioned problems when it is used by itself or on top of cover liner systems.

BENEFIT/COST RATIOS, BARRIER LAYER OPTIONS					
Design alternate	Description	Overall benefit	Estimated cost (dollars/sq ft)	Benefit/cost ratio	Ranking in group
One Barrier Layer					
A	CCL	36	0.70	51	3
B	GM	64	0.70	91	1
C	GCL	46	0.70	66	2
Two Barrier Layers					
D	GM/CCL	58	1.40	41	2
E	GM/GCL	66	1.40	47	1
Three Barrier Layers					
F	GM/CCL/GM	71	2.10	34	2
G	GM/GCL/GM	77	2.10	37	1

FIGURE 8 - INDEPENDENT STUDY FOR LANDFILL BARRIER OPTIONS, SEE TWO BARRIER LAYERS (CIVIL ENGINEERING, "BETTER COVER UPS", PG 55, MAY1992)

The Secondary Design used an HDPE/GCL combination which is easier to install the GCL than the Admix layer but was less traditional; and the two liners are directly interfaced creating less chance of surveying a catastrophic failure caused by puncture through both by an extreme occurrence. The use of GCL's is relatively new and that's another reason it was used as a secondary design layer.

After determining the preferred synthetic man-made material, specific details on physical characteristics of the materials were again directly analyzed against one another. The final choices are discussed in the Results Section under Materials Descriptions.

General Liner Information is described below:

For the primary design, the manmade liners analyzed included the High Density Polyethylene (HDPE) liners, woven and nonwoven fabrics, and nonwoven fabric separated by a polyethylene grid or net called Gundnet XL-14. The secondary design included all the synthetic man-made materials from above but replaced the natural Admix layer with a Geosynthetic Clay Liner(GCL).

For the primary design, the geosynthetic liners and natural materials included using the on-site sand/silt/alluvial soil for the top soil layer. This top layer was used for used for

vegetation growth, animal protection, and retaining part of the moisture in and away from the top liner materials. A Woven fabric material was selected for separating this top soil from the rock drainage below and protection from plant roots and animals. The woven fabric material prevented the top soil from migrating downward as well as the frictional grab strength of the woven material providing stability to the cover as a whole. Then two layers of nonwoven fabric separated by a drainage grid(Gundnet XL-14) were below that with. The nonwoven fabric along with the polyethylene grid will protect the HDPE from rocks protruding into it. The nonwoven also protected the HDPE from rocks , then the High Density Polyethylene (HDPE) was used as a permanent impermeable liner to keep all moisture from contacting the Admix Layer and the hazardous waste below. The Admix liner consisting of silt, on-site soil and 12% bentonite was used to provide a uniform base covering the waste and suitable for laying the HDPE on top of it.

The Secondary Design included all the above mentioned materials except for the Admix liner which was replaced with a Geosynthetic Clay Liner(GCL). This product is called Claymax 500SP and is two geosynthetic liner materials with bentonite clay sandwiched between them. A base soil layer of one foot thickness is laid above the waste providing a smooth surface to lay the Claymax on. This GCL allows easier installation and more cell space in the landfill.

RESULTS

RESULTS:

The following section describes general and technical specifications concerning the cover design and the individual liner materials in each. Refer to Appendix C for these specifications. The detailed construction methods can be obtained from each liner manufacturer. Specific construction methods will be in the Recommendation Section to ensure the integrity of the cover design. Without adherence to proper installation procedures, the lifespan and functionality of the cover design will be compromised. Proper maintenance will also provide proper long term cover functionality.

PRIMARY AND SECONDARY LINER DESIGN, GENERAL SYSTEM ITEMS:

This section provides a general description of the Project W-025 Radioactive Mixed Waste (RMW) Landfill final cover system. This system has been designated to prevent migration of precipitation Leachate into the landfill. The Project W-025 Landfill is located in The 218-W-5 burial ground as shown in plan view on Figure 3. Figure 6 and Figure 7 also show the cover's configuration.

The final cover system was designed to meet all Federal and State regulatory requirements, specifically EPA 40 CFR to 265 and Washington Department of Ecology WAC 173-303. The Functional Design Criteria (FDC) specified the minimum design criteria for the following items:

- o Comply with Federal (RCRA) and Washington State Department Of Ecology regulations.
- o Capacity of Approximately 40,000 cubic feet of waste.
- o Prevent migration of precipitation leachate into the landfill.
- o A permeability greater than or equal to that achieved by Golder Associate Inc.'s liner design.
- o Range of Operating Conditions- Year round operation, withstand construction and long-term stresses, accommodate 24 hour, 25-year rainstorm.
- o Degree of reliability - function safely and effectively throughout operating and post closure period with minimum maintenance.
- o Intended Life - operational phase plus 30 year post closure monitoring phase.

COVER SYSTEM DESCRIPTION:

The landfill final cover system (Reference Figure 1) included the following components from top to bottom respectfully.

- o Top soil layer: 2.5 feet-thick native soil layer, also referred to as the operational layer.
- o Woven Material: Synthetic layer to prevent silt infiltration into the primary drainage system.
- o Primary Drainage System: 1.0 foot-thick layer of cobbles.
- o Geonet: Synthetic layer which will divert migrated precipitation and protect the HDPE liner.
- o High Density Polyethylene Liner (HDPE): Liner of a 60 mil textured synthetic which acts as the primary impermeable layer in the cover.

- o **Admix Layer:** A 2.0 foot-thick layer consisting of 12 percent bentonite compacted to a minimum of 85 percent saturation for the cover design.

General descriptions concerning the layers are below with the specific detailed man-made liners and bentonite following in the Material Description Section. The liner material costs for both the Primary and Secondary Liner Design sections are in the Material Cost Section.

Top Soil Layer(Operations Layer)

The operations layer material consists of on-site granular soil which is reasonably well grade and conforms to one of the following Unified Soil Classification System designations: GM, GC, SW, SM, SP, or SC. Material placed on liner of the landfill has a maximum particle size of four inches, with large particles embedded in a finer soil matrix. Material placed on the side slopes has a maximum particle size of one inch.

The purpose of the topsoil layer is to protect the underlying liner components from equipment damage during landfill construction and operation. On the side slopes, this layer will also protect the admix layer from freezing and dessication cracking.

Woven Material

This woven slit film material separates the top soils layer and the Rock Drainage Layer and functions as stabilization, soil separation, and reinforcement. The "200ST" Woven Slit Film separates the top soil layers and the Rock Drainage Layer and functions as stabilization, soil separators, and reinforcement. The 200ST Woven Slit Film will prevent the easy migration of soil, plant roots, and burrowing animals from penetrating downward into the Rock Drainage Layer. Breaking through this material may prevent the efficient drainage of water entering the rock drainage layer as well as compromising the slope angle of the top soil layer. Proper top soil maintenance must then be done to prevent further damage to the slit film. The water contained within the top soil layer must also be held in as long as possible to allow for slow infiltration and transpiration and evaporation back out to the environment. Reference the more detailed material description in the "Material Description Section".

Primary Rock Drainage Layer

Indigenous rocks screened from native soils will be used to create a one foot thick layer to promote drainage from the infiltration of surface water. Stones will range in size from three quarters of an inch to three inches in diameter.

Geo Net Description:

The "Fabric-Net" is a Gundnet XL-14 sandwiched between two 6 ounce sides of woven Geo textile Composites. The Gundnet XL-14 is a polyethylene mesh that is very strong but pliable and has very small openings in its mesh structure and will prevent the individual rocks from the rock drainage layer to protrude or puncture into High Density Polyethylene (HDPE) Liner. The Woven Geotextiles on both sides of the Gundnet XL-14 are 6 oz/sq yds and provide protection from rocks with sharp edges from penetrating into

the HDPE liner as well as provide a drainage media. One of the most outstanding features of the woven geotextile fabric is its strong frictional cohesiveness interface between itself and the Frictional Surface of the HDPE layer below creating a stability interface between the two allowing the structural integrity along the steep side sections of the cover. Reference the more detailed material description in the "Material Description Section".

HDPE Liner:

The HDPE liner acts both as an impermeable leachate barrier as in the bottom liner and as a flow surface below the drainage layer. The precipitation collection system is located in both an external and internal drainage trenching system. The geomembrane used for the cover in the liner system consists of a textured, or frictional surface, 60 mil HDPE geomembrane, designed to provide relatively high friction angles with geotextiles. This will enhance the cover's stability on these 3H:1V slopes. The HDPE will have chemical resistance and ultraviolet resistance but neither is a real concern for this cover design.

Admix Layer

An admix liner, consisting of a two foot-thick compacted soil/bentonite admixture, is located immediately beneath the HDPE liner in the cover design. The admix liner consists of a silty sand(Eolian Deposit) from the landfill excavation mixed with a nominal twelve percent sodium bentonite, by weight. The in-place permeability of the admix liner is 1×10^{-8} cm/sec or less, as determined by CQA testing (Golder Associates Inc., 1994).

The upper surface of the admix liner was trimmed to the design grades and tolerances as shown on the construction drawings. The surface was then rolled with a smooth steel drum roller to remove all ridges and irregularities to prepare a smooth uniform surface on which to place the geomembrane liner.

GENERAL COVER DESIGN CONSIDERATIONS:

Stresses From Installation or Construction Operations

The HDPE liner is temperature sensitive, expanding and contracting as liner temperatures increase and decrease. Thermally induced stresses can develop in the liner if deployment and anchoring occur prior to a significant decrease in the liner temperature. The maximum potential liner thermal stress typically occurs during construction prior to placement of the covering layers. Under worst case conditions, the strain in the liner is estimated to be approximately one percent, creating a tensile stress of approximately 1000 pounds per square inch, which is well below the yield strain and stress of the HDPE geomembrane liner. Information concerning the analysis for the thermal stress is presented in Appendix C.10 of the Design Report(Golder Associates Inc., 1992).

A puncture analysis was conducted disregarding the presence of the geonet. The analysis, which incorporated expected construction vehicle ground pressures and assumed the drainage gravel gradation listed in the construction specifications, resulted in a factor of safety of three against puncture of the geomembrane liner. Details of the

puncture analysis are presented in Appendix C.27 Design Report (Golder Associate Inc., 1992).

Tension induced by liner component load transfer is not anticipated to occur since the liner interface coefficients of friction are higher than the side slope angles. The liner component interface strengths, laboratory direct shear tests, which were performed by Golder

Associates Inc., are summarized in the Design Report (Golder Associates Inc., 1992) and the QCA Report (Golder Associates Inc., 1994). Both static and dynamic stability analyses were performed on the side slope liner components.

Stresses Resulting From Operating Equipment:

Loads on the liner system due to operating equipment are expected to be less severe than those generated by construction equipment for two reasons: First, landfill operations equipment will probably be of lighter weight than construction equipment, and secondly, the presence of the 2.5 foot-thick operations layer will tend to dissipate stresses produced by the operating equipment. For information regarding the stress analysis from equipment refer to Appendix C.25 of the Design Report (Golder Associates Inc., 1992).

Stresses Resulting From Settlement, Subsidence, or Uplift:

Total settlement of the liner system will be a combination of the subgrade elastic and the admix consolidation settlements. It is anticipated that a total settlement to be about four inches, and the maximum differential settlement is estimated to be approximately in inch; settlement of the subgrade and consolidation settlement of the admix have been calculated to be equal. The synthetic liner components are highly elastic, and the resulting strain produced by the differential settlement of one inch is very small, approximately 0.02 percent. Settlement analysis for the liner system is available for review in Appendices C.16, C.12, and C.18 of the Design Report (Golder Associates Inc., 1992).

Settlement within the cover design system will be negligible because materials used in the cover design are similar as the liner system designed by Golder Associates Inc..

The greatest possibility of settlement is within the waste cells. Strict loading procedures are suggested to ensure the integrity of the Final Cover System. To minimize cell consolidation, compaction equal or to exceed the compaction rates of the Admix Layer is advised. The compacted admix liner is suggested to be placed and compacted to a minimum of 85 percent saturation. The potential for subsidence-induced stress is believed to be negligible based on the following information.

- o The soils underlying the landfill site tend to be coarse-grained sands and gravels which are not subject to piping which can cause transport of soil and resulting subsidence.
- o The ground water level is deep, approximately 235 feet below the base of the landfill, and as a result will not affect bearing soils.
- o No mining or tunneling has been noted, and no large quantities of ground water will be withdrawn from the underlying aquifer. Even if the ground water level was

- lowered substantially and consolidation occurred in the aquifer, local site-specific subsidence would be negligible due to the depth of the ground water.
- o The native soils are well graded and density is relatively high.

The potential for stresses resulting from uplift on the liner system is also expected to be negligible. The seasonal ground water level is very deep, and higher-elevation perched water tables are unlikely due to the absence of aquitards in the coarse-grained Hanford formation, which underlies the landfill. The coarse-grained nature of the Hanford formation also promotes rapid, primarily vertical, infiltration, which means it is unlikely that infiltration from outside the landfill boundary will be transported laterally underneath the landfill liner system. The uplift nature of any gasses formed within the landfill over a period of time will be negligible due to the gas venting system. The potential for uplift is also discussed in Appendix C.20 of the Design Report (Golder Associates Inc., 1992).

Liner System Side Slope Stability:

Both static and dynamic stability analyses were performed for each side slope liner component interface using laboratory direct shear test residual strength parameters for both friction angle and adhesion. The dynamic analyses were conducted using a horizontal acceleration of 0.12 g as required in the relevant standards (DOE, 1989). See Figure 6 and Figure 7.

The interface between the geotextile and top soil layer proved to be the critical interface, with static and dynamic factors of safety of 1.8 and 1.3 respectively. Details of this analysis are presented in Appendix C.9 of the Design Report (Golder Associates Inc., 1992).

Subsurface Exploration Data

Due to the sensitivity of the Hanford Site, our design team was denied access to soil samples, so soil analysis was not possible. All assumptions for the soil types and soil strengths are based on test information gained by analysis by the soil laboratory at Golder Associates Inc. In addition, Golder performed a field study which was carried out in November, 1989 which included an evaluation of borrow soils in Area 1, about 1.5 miles west of the W-025 landfill site, and the McGee Ranch, located about one-half mile north of the Yakima Barricade (Golder Associates Inc., 1992). The following sections summarize the different methods of subsurface exploration conducted and results of each included.

Grain Size Analysis:

As previously mentioned, all geotechnical investigation and testing was performed in November, 1989, by Golder Associates Inc. Grain size analyses were performed on soil samples from each potential borrow area, including a composite sample from seven test pits at the Project W-025 landfill site. The grain size curves, presented in the Site Investigation Report (Golder Associates Inc., 1989), indicated that the upper soils at the Project W-025 landfill site and Area 1 are silty, fine to medium sands and are classified as

SM based on the Unified Soil Classification System. The borrow soil at the McGee Ranch site is classified as a sandy silt (ML).

Atterberg Limits:

Atterberg limit tests were conducted on samples collected from the Project W-025 landfill site and both alternative borrow areas. All of the samples exhibited non plastic behavior.

Natural Moisture Content:

Soil samples for moisture content analyses were collected at the Project W-025 landfill site and at the alternative borrow sites. The samples were sealed at the time of collection to prevent moisture loss, refrigerated overnight, and tested the following morning in accordance with ASTM D 2216. The results from the Project W-025 landfill and Area 1 sites indicated moisture contents ranging from two to four percent. The moisture content analyses from the McGee Ranch site ranged from two to eight percent.

Stability of Landfill Cover Slopes:

In granular, cohesionless, and drained soils such as the ones that exist at the Project W-025 Landfill, the stability of the slope is related to the maximum slope angle. Therefore, an infinite slope analysis method was used by Golder to determine both static and dynamic side slope stability. The dynamic analysis assumed a horizontal acceleration of 0.12 g as required in the relevant standards (DOE, 1989).

The results for the 3H:1V cut slopes in the subgrade indicated factors of safety for static and dynamic stability of 2.4 and 1.7 respectively. These values are significantly higher than the required design values of 1.5 and 1.1. Since the same or very similar soil types are being recommended for the side slopes of the cover design, the stability analysis done for the subgrade by Golder Associate Inc. is used for the same results.

Potential Gas Pressures:

Gas pressure exerted externally on the liner system is expected to be negligible, since no gas generating material (i.e., organic material) will be placed in the landfill. If any gas was generated within the landfill, a venting system at the peak of the cover will collect and expel the internal gasses. Internal gas pressure buildup, is not anticipated, because the leachate collection system and vertical riser pipe are vented to the atmosphere and will dissipate any gas.

Seismic Conditions:

Potential hazards from seismic events include faulting, slope failure, and liquefaction. Disruption of the landfill by faulting is not considered a significant risk because no major faults have been identified in the LLBG (DOE, 1988c), only one central fault at Gable Mountain on the Hanford Site shows evidence of movement within the last 13,000 years (DOE, 1988c). The potential for slope failure is low, as discussed previously. Liquefaction

occurs in loose, poorly graded granular materials that are subjected to shaking from seismic events. Saturated soils are most susceptible because of high dynamic pre pressures that temporarily lower the effective stress. During this process, the soil particles are rearranged into a more dense configuration, with a resulting decrease in volume. The foundation materials at the Project W-025 landfill site are not considered susceptible to liquefaction because they are well graded, unsaturated, and relatively dense.

Subsidence Potential:

Subsidence of undisturbed foundation materials is generally the result of dissolution, fluid extraction (water or petroleum), or mining. The potential for subsidence is considered to be negligible based on the following information:

- o The soils underlying the landfill site are coarse-grained sands and gravels which are not subjected to piping which can cause transport of soil and resulting subsidence.
- o The ground water level is deep, approximately 235 feet below the base of the landfill, and as a result will not affect bearing soils.
- o The soil and rock types below the landfill site are not soluble.
- o No mining or tunneling has been noted, and no large quantities of ground water will be withdrawn from the underlying aquifer. Even if the ground water level was lowered substantially and consolidation occurred in the aquifer, local site-specific subsidence would be negligible due to the depth of the ground water below the landfill.
- o The soils are well graded and relatively dense.

Liner System, Liners:

The following sections contain information about synthetic and soil liners for the Project W-025 landfill final closure cover.

Synthetic Liners:

The liner system for the Project W-025 landfill is described in Implementation and the Results Sections. The geosynthetic materials considered are summarized in the decision matrix (Appendix C).

Tension in Side-slope Components:

Tension in side slope liner components would develop if the shear strength at any of the interfaces was low enough that the overlying components would start to slide. However, the use of textured HDPE, together with a bonded geocomposite for the secondary drainage layer, is expected to produce interfaces with sufficiently high strength that sliding will not occur.

Thermal Stresses:

A worst case analysis was performed for an HDPE geomembrane similar to the one suggested for the final closure cover on the side slopes for the landfill, anchored at both ends, with no slack, and subjected to a temperature drop of 100 F. Under these extreme conditions, the maximum tension in the liner was calculated to be about 60 pounds per inch of width, will below the required yield stress of 144 pounds per inch (Golder Associate Inc., 1993). During construction it is suggested that the HDPE be installed with some slack, and consequently maximum stresses are expected to be much lower. Also, thermal stresses will be substantially less because of the 2.5 foot-thick top soil and 1.0 foot thick primary drainage layers, which act as insulators and reduce the temperature change to a fraction of that experienced by the exposed HDPE.

Settlement Stresses:

The maximum differential settlement between the edges and the center of the landfill is estimated to be about one inch. Refer to Appendices C.16, C.17, and C.18 of the Design Report (Golder Associate Inc., 1992a). The resulting strain in the geosynthetics on the side slopes of the cover can be considered negligible. Geonets and geotextiles have high elongations properties; for example, the manufacturers data for grab strength of the textured geotextile corresponds to elongations of about 50 percent.

Seam Strength:

Strength requirements for factory and field seams in HDPEs are similar to those recommended for use in the cover design, the data is presented in the Material Specifications (Golder Associates Inc., 1993a). In summary, seams are required to have at least the strength of the intact HDPE. During seam strength testing, failure must occur in the adjacent geomembrane rather than through the seam itself. With this criterion, seams in the 60 mil HDPE liner are expected to accommodate any stresses that the intact liner material can support. Seams will be tested during construction in accordance with installation requirements and Westinghouse Hanford criteria. All seams must pass or be repaired until a passing result is achieved.

Seaming requirements for the geonet are not as critical because this system is designed for drainage not impermeability. The materials will be overlapped sufficiently to provide complete areal coverage, and relatively light seams will be used to adequately hold the panels in position during construction. After the lining system is completed, seam strength requirements must be met.

Synthetic Liner Bedding:

The synthetic liner system is in contact with the compacted admix layer. This provides a very smooth and stable surface for the application of the geosynthetic membrane.

The 60 mil HDPE is in direct with the compacted admix layer. This layer consists of a silty fine sand with 11 to 14 percent bentonite by weight. this type of fine grained material is typically used for clay liners overlain by HDPEs and no problems related to HDPE mechanical integrity are expected in this configuration. It is suggested that all materials to be used should come from the McGee Ranch due to its sandy silt characteristics.

CONSTRUCTION SPECIFICATIONS:

Construction requirements for major components of the cap cover design are summarized below. Additional detail regarding methods and materials are presented within the document (See Tables in Appendix C for material specifications).

Soil Liners:

The soil and bentonite are to be thoroughly blended and moisture conditioned so that the admix layer is relatively uniform and homogeneous throughout. The admix layer is to be placed in 8 to 10 inch loose lifts and compacted so that the compacted lift thickness is 6 inches or less, except that the first lift of the layer must be at least 12 inches thick (loose) to prevent damage to the storage cells during compaction. Each new lift will be kneaded into the previously placed lift. The admix should be compacted to at least 90 percent maximum dry density with a coexisting moisture content ranging from 1 to 5 percent above optimum. The methods for admix preparation, type of compaction equipment, number of passes, and other details of the placement process were determined by constructing a test full section prior to placing admix in the landfill. This test was performed by Golder Associates and due to the fact that the same admix is being used in the cap design the same conclusions can be used (See Section 02224, Golder Associates Inc., 1993a).

Geosynthetic Liners:

To protect the overlaying HDPEs, the admix surface is to be smooth and free of rocks, stones, sticks, roots, sharp objects, and debris of any kind. In all cases, the HDPE liners are to be rolled with the length of the roll parallel to the slope. No horizontal seams are allowed on the slopes. Adjacent panels are to be overlapped 3 to 6 inches and thermally seamed using fusion methods. Seams are to be continuously inspected using vacuum box and air pressure tests. Destructive seam tests are to be used at least once every 500 feet of seam. Acceptance criteria for seams are discussed in the Material Description Section and Appendix C.

Liner Repairs During Operations:

Because of the one foot thick rip-rap layer and 2.5 foot thick top soil layer, damage to the liner system is not expected. If damage does occur, the top soil layer should be removed laterally as far as required. Underlying layers should also be removed until an undamaged layer is encountered. The damaged layer will then be repaired and replaced from the lowest layer upwards using similar procedures to those employed during construction. Most repairs to the HDPEs will be performed using a patch which will be placed, welded, and tested by CQA personnel.

MATERIAL COSTS

RESULTS SECTION**PRIMARY AND SECONDARY DESIGN'S LINER MATERIAL COSTS****PRIMARY DESIGN MATERIAL COSTS:**

The following materials are those that can not be directly obtained from the surrounding vicinity of the job site. Man-made layers as well as bentonite for the bottom Admix layer are shown below. Man-made layers for the Primary Design were based on 244,000 sq. ft of coverage including 15% which was added for installation wastage. This 15% wastage value provides conservative estimates when applying a liner product. Any excess material not used in the laying of the High Density Polyethylene Liners may possibly be negotiated for return to the on-site installation crew. Most liner installation allows 10-15% for wastage so these figures are accurate estimates. The general names of the liner material along with the specific product name is below and shown in the order of the design from a top-down approach. The costs include installation, shipping, and other transportation costs. Details or specifications of specific liners are shown in decision matrixes and discussed in more detail in the Appendix C.

Woven Slit Film For Separating Top Soil Layer and Rock Drainage Layer

Product: "200ST" Stabilization Slit Film **Cost- \$10,000**
 Company: Synthetic Industries supplied by Northwest Linings &
 Geotextile Products, Inc., Kent, WA

Geotextile/Fabric Net for Separating Rock Drainage Layer and HDPE Liner

Product: "Fabric-Net(Gundnet/Geotextile) Composite", (2 sides **Cost- \$109,800**
 Geotextile Woven Polyethylene Composite surrounding
 Fabric-Net XL-14)
 Company: Gundle Lining Systems Inc.

High Density Polyethylene(HDPE) Liner Separating Gundnet Geotextile and Admix Layer

Product: "Friction Seal 60 mil HD 2 Sides" **Cost- \$103,000**
 Company: National Seal Company

Bentonite for Bottom Admix Layer(12% ratio of bentonite to site soil))

Product: "Black Hill's Gel" **Cost- \$154,215**
 Company: Black Hill's Bentonite Company
 Cost is dependent on transportation.

Primary Design Total Cost = \$377,000

SECONDARY DESIGN MATERIAL COSTS:

The following materials or man-made layers for the Secondary Design are the same as for the Primary Design. The exception in the Secondary Design is replacing the 12% bentonite included in the Admix layer with a man-made Geosynthetic Clay Liner (GCL). This GCL is still laid upon a standard depth(approx. 12 inches compacted) of soil allowing for a flat and stable installation of the GCL. The GCL consists of bentonite sandwiched between two layers of geotextiles. As in the Primary Design, the man-made GCL for the Secondary Design is also based on 244,000 sq. ft of coverage which includes 15% added for wastage. This provides a conservative estimate when applying a GCL liner. The GCL will be easier to install and provide other advantages over the Admix layer. The costs include installation, shipping, and other transportation costs. Details or specifications of the specific GCL liner are in decision matrixes and discussed in more detail in Appendix C.

Primary Layers (Same as Primary Design) **Cost- \$222,800**

Geosynthetic Clay Liner (GCL) Liner Directly Below HDPE Liner

Product: "Claymax 500SP GCL"

Cost- \$ 99,000

Company: James Clem Corporation

Plus adding .25 lb/sq. ft of bentonite added at overlapped seams. **Cost- \$ ****

6 inch overlap equals .25lb actual per 2 feet of liner interface so the estimated bentonite required is to cover 17,200 linear feet plus two vents or roughly 2500 pounds of bentonite which is a nonconservative figure.

Note: Minus cost of Admix Layer Preparation and installation.

** Cost must be determined by Hanford Corp.. Can negotiate by contacting Black Hill's Bentonite in Wyoming or CETCO Corp..

Secondary Design Total Cost = \$321,800

MATERIAL DESCRIPTIONS

RESULTS SECTION - MATERIAL DESCRIPTIONS

PRIMARY DESIGN MATERIAL DESCRIPTIONS:

Reference Decision Matrices in Appendix C.

The following materials are those contained within the Primary Design. The liners are based on 244,000 sq. ft of coverage including 15% wastage. Products or materials are discussed from the top downward to the bottom layer in the Design Configuration.

Product: "200ST" Woven Stabilization Slit Film

Company: Synthetic Industries Inc.

Reference Specifications Sheet in Appendix C. Supplied by Northwest Linings & Geotextile Products, Inc.; Attention Rick W. Newton; 20017 89th Avenue South; Kent, WA 98031; Phone (206) 872-0244; Fax (206) 872-0244

The "200ST" Woven Stabilization Slit Film separates the top soil layers and the Rock Drainage Layer and functions as stabilization, soil separators, and reinforcement. The 200ST Woven polypropylene Slit Film will prevent the easy migration of soil, plant roots, and burrowing animals from penetrating downward into the Rock Drainage Layer. Breaking through this material may prevent the efficient drainage of water entering the rock drainage layer as well as compromising the slope angle of the top soil layer. Proper top soil maintenance must then be done to prevent further damage to the slit film. The water contained within the top soil layer must also be held in as long as possible to allow for slow infiltration and transpiration and evaporation back out to the environment. This is done in the Hanford environment by the slow seasonal changes of moisture being held and transpired from the sand/silt soil in the top layer. The permeability of the slit film is adequate (.13 cm/sec TYP) to allow water reaching it to drain into the drainage layer. This prevents water buildup below the top soil layer which may cause erosion and land slide effects between the top soil and the slit film material. The job site's glacial alluvial soil contained weathered rock lacking sharp edges and should be compacted prior to laying the slit film on top of it. This will prevent post large differential settling movements. This also fills large void spaces in the rock layer making it even more inaccessible to burrowing animals, however, this is very unlikely anyway. Compacted and leveling the rock layer will prevent tensile forces causing unwanted slit film elongation. The grab elongation properties of the slit film (200ST) are 25% in both machine and cross machine directions. The 200ST has an advantage of providing stabilization but with adequate permeability features due to the .425mm to .600 mm openings (ASTM D-4751 Test Method). The reduction in permeability was not dramatically reduced by selecting the 200ST used for stabilization instead of a slit fence such as product 910SC. The permeability of the two products is .13 cm/sec and .23 cm/sec TYP with flow rates of 17 gpm/sq. ft. and 26 gpm/sq. ft., respectively. We recommend a roll width of 180 inches (15 feet) and a roll length of 360 feet. This will allow proper overlapping of the cover's steeper sloped sides up to the top or crown of the cover. The seams shall be overlapped and laid from the bottom or steeper sides slopes of the cover upward to the cover's crown. This working backward will allow that longer segments of the slit film are at the critical steeper slope areas and shorter pieces will be near the crown area. The 360 feet, however, should allow for stagger pieces to almost cover the crown areas. Overlaps will be like that

of shingles a house at a top-down approach both for the cover's crown and also in the direction of the primary water flow due to rain, snow, etc.

Synthetic Industries is the second largest manufacturer of polypropylene textile fibers and fabrics in the world. It has over 10 years experience and over 100 million square yards of woven and nonwoven geotextiles have been produced. Stabilization and reinforcement of the woven slit film geotextiles is obtained by their high strength at low elongation (high tensile modulus) which distribute loads and prevent rutting. They also provide and maintain separation of subgrade soils as in our top soil and the aggregate rock layer used for drainage. Their reinforcement is the containment of the rocks in direct contact with their fibers at the interface of the slit film and the rock drainage layer on the steeper slopes of the design. The 200ST product is used in highway designs, and meets or exceeds the AASHTO M288-90 medium survivability levels. The fibers contain overland flow so they will reduce sediment run-off or rutting in the top soil.

Northwest Linings can answer most questions but the Synthetic Industries Construction products Division can be reached at 1-800-621-0444 or fax #(615) 8999-7619.

"200ST" Woven Stabilization Slit Film

Material Costs: 244,00 sq ft x \$.041/sq ft = \$10,000

Shipping Costs: Included in Material Costs

Installation Costs: Considered \$0 because the installation can be conducted by Kaiser Engineering at Hanford (Overhead Costs)

Product: "Fabri-Net(Gundnet/Geotextile) Composite"

Company: Gundle Lining Systems, Inc.

Reference specifications sheet in Tables in Appendix C.

(2 sides 6 oz. Woven Geotextile Composite surrounding Gundnet XL-14)

Gundle Address: 19103 Gundle Road; Houston, Texas 77073; Phone 800(435)-2008;

Fax # (713)875-6010.

The "Fabri-Net" is a Gundnet XL-14 sandwiched between two 6 ounce sides of woven Geo textile Composites. The Gundnet XL-14 is a polyethylene mesh that is very strong but pliable. The Gundnet XL-14 has very small openings in its mesh structure and will prevent the individual rocks from the rock drainage layer to protrude or puncture into High Density Polyethylene (HDPE) Liner.

The Woven Geotextiles on both sides of the Gundnet XL-14 are 6 oz/sq yds and also provide protection from rocks with sharp edges from penetrating into the HDPE liner. One of the most outstanding features of the woven geotextile fabric is its strong frictional cohesiveness interface between itself and the Frictional Surface of the HDPE layer below; which acts like "velcro". The stability of the interface between the two will allow the structural integrity along the steeper side sections of the cover. The friction coefficient angle increases when using the polyethylene geotextiles rather than the polyester geotextiles on the specific Friction Surface HDPE we are using. The strength of the polyester is suppose to be stronger but the price is usually higher. The non-woven geotextile fits the frictional purposes used in the designs structural stability and the cost was legitimate. Outstanding structural integrity features are obtained by preventing slope failure by holding the HDPE and Fabri-Net layers together even when differential settlement causes increased tension on liner materials.

The Gundnet XL-14 achieves unsurpassed efficiencies for fluid flow as a drainage layer in following installation. Its performance qualities include high resistance to chemicals, rodents, and microorganisms. In addition, the overlapping of two polyethylene strands has excellent tensile strength and resistance to strand layover thus providing protection from rocks protruding into the HDPE liner. The Fabri-Net consists of the two geotextiles heat bonded to the Gundnet on both sides. The geotextiles used can be specified but the standard geotextile used is excellent for friction adhesion to the textured HDPE in the design. The only variance to the top geotextile would be to heat bond on a non-woven polyethylene layer to further protect the incidence of any rocks with sharp edges attempting to protrude into the HDPE. The current design is using the standard sample of Fabri-Net. The interface gripping of the Fabri-Net and the textured HDPE works like velcro. An exceptionally high coefficient of friction is achieved and maintained, enhancing slope stability. We recommend the 14 foot wide by 200 foot long rolls to be used in the cover design. This allows for proper overlap and to efficiently cover the required square footage of the cover. Fabri-Net is simply unrolled to form a blanket on top of the frictional or textured HDPE. No heavy equipment is needed to lay it down and Kaiser Engineering working within Hanford can do the installation. Immediately after seaming the HDPE liner, the Fabri-Net can immediately be installed. This is usually not the case for sand or gravel layers which must be entirely in place before grading of the sand is allowed. The Fabri-Net installation will take only a few days where the sand or gravel may take over a week. Heavy equipment is not needed and the ability and thickness of the Fabri-Net to replace sand or gravel reduces the thickness required and increases the capacity of the landfill. A non-woven polyethylene geotextile can replace the top woven polyester geotextile to possibly provide more protection to the HDPE but this may not be necessary.

Product: "Fabri-Net(Gundnet/Geotextile) Composite"

Material Costs: 244,00 sq ft x \$0.45/sq ft = \$109,800

Shipping Costs: Included in Material Costs

Installation Costs: Considered \$0 because the installation can be conducted by Kaiser Engineering at Hanford(Overhead Costs)

High Density Polyethylene(HDPE) Liner Separating Gundnet Geotextile and Admix Layer

Product: "Friction Seal 60 mil HD 2 Sides"

Company: National Seal Company

Reference Specifications Sheet in Tables in Appendix C.

Supplier and Distributor is Northwest Linings & Geotextile Products, Inc.; Attention Rick W. Newton; 20017 89th Avenue South; Kent, WA 98031; Phone(206) 872-0244; Fax (206)872-0244

The Friction Seal's textured surface increases the safety factor for steep slope designs by increasing friction angles between layers. As a result, the steeper slopes increase the capacity of the landfill. In our design, the steepest slopes are around 18 degrees but the longest sections are saved for last to assure the most frictional stability possible. The Friction Seal HD has excellent stress crack resistance, good puncture properties and multi-axial seam properties under proper design, and excellent ultraviolet and chemical resistance. The high coefficient of friction is 32 degree friction angle for a non-woven geotextile under 55 lbs/sq ft adhesion and for a clay liner, 29 degrees and 150 lbs/sq ft, respectively. Tests were run on a 12 in by 12 in direct shear box at strain rates of 0.04 in./min on the soil profiles and 0.20 in./min on the geotextile profile. Normal compressive loads of 3 psi, 6 psi, and 9 psi were used. The National Seal Company's(NCS's) manufacturing process adds a friction coating to an HDPE allowing for a more consistent and accurate thickness. Variance of the roughness by adding the friction onto a geomembrane provides larger differential thickness values than a single textured sheet produced by a single coextrusion method. NCS's secondary manufacturing method uses a base sheet of plus or minus 5% and this provides for ensuring proper frictional properties being added. The Friction Seal offers a superior coefficient of friction with soils and geosynthetics; which are used in our Primary and Secondary Designs. The frictional adhesion is increased when the weight of our top soil and rock layer push downward onto the Friction Seal and the Geotextile. As a result, this weight can push the Friction Seal's critical failure plane down into the Admix Layer improving slope stability. This will put safety into the steeper sides of our design and assure against material slippage. This is also helped by the overlapped seams being shoved into the Admix Layer. Friction Seal is produced with 6"-10" smooth edges on both sides of the sheet, top and bottom. The smooth surfaces provide for a better extrusion weld at the seams equaling the high double welding as in smooth HDPE Liners. Some other companies may weld the textured seam material together, which causes a decrease in welding speed and therefore an increase in "squeeze out" due to melt-through of the friction coating to the base sheet. The smooth edges also permit verification of the core's thickness and strength before installation. A double extrusion weld is recommended for our design. The seams can be 6 to 8 inches but the great coefficient of friction provided by the friction seal and the geotextiles will prevent movement in the areas of steeper slopes. If larger seams are desired at installation, the larger 8 inch seam will be adequate. The use of friction coating HDPE liners is commonly used in closure covers installed today, they increase slope stability and increase landfill capacity.

In the NSC's Construction Quality Control (CQC) Laboratory, the CQC lab team develops new welding equipment, investigates improved methods of seaming and provides welding training.

For example, a two-year intensive research and development effort has culminated in the Smart Mouse, a computer process control fusion welder, which is recognized as the most technologically advanced welder in the industry. The heart of the new welder is its process control computer, which measures and records critical parameters that can affect welding quality. The Smart Mouse allows NSC to gather and use real-time data regarding welder performance and the process of joining two liners in the field. A double extrusion weld is one in which overlapped liners seams will have a welded separation of around six inches.

Using the latest equipment, the lab also provides technical assistance to the field installation teams. In fact, on all National Seal installations, a specific technician is devoted to construction quality control.

Product: "Friction Seal 60 mil HD 2 Sides" **Company: National Seal Company**

Material Costs: 244,00 sq ft x \$0.41/sq ft = \$100,400

Shipping Costs: 244,00 sq ft x \$0.01 or \$0.0125/sq ft = \$2440 to \$3050

May negotiate on shipping costs since the distributor is in Kent, WA.

Installation Costs: Must be conducted by National Seal Company or qualified company directed by National Seal Company. Installation costs are included in Material Costs.

Installation around two boots is assumed to be included so negotiation with the installer must be carried through by Westinghouse.

Total HDPE Costs Average is equal to \$103,000.

Another product which was analyzed but not selected was the SLT "Friction Flex Textured 60 mil HD". This product is manufactured and distributed by the SLT company and is double sided textured 60 mil HDPE. This product would make an excellent alternative for similar applications. Information regarding the SLT product is shown in the Decision Matrix in Appendix C.

Primary Design: Bentonite for Admix Layer(12% ratio of bentonite to site soil)

Product: "Black Hill's Gel"

Cost- \$151,900

Company: Black Hill's Bentonite Company

Address: 55 S. Salt Creek Hwy; Casper, Wyoming; phone (307)265-3740

and mailing address is P.O. Box 9, Mills, Wyoming 82644; Fax 307-235-8511

Bentonite was used in the bottom liners of the landfill and the top liners must equal the same permeability values so we matched the 12% bentonite used in the bottom liner. We selected a very high grade bentonite to assure this. The permeability values of 1×10^{-7} cm/sec is expected but tests show initial values to be 1×10^{-8} cm/sec. Tests conducted on bentonite are subjective and the specifications for the bentonite in the bottom liner were stated to be high but the selected bentonite satisfies this requirement as stated in the bottom liner specifications. The Admix soil consisted of silty sand(Eolian Glacial Deposit) mixed from the landfill site's excavation or the surrounding area and should be mixed with a "pug mill" just prior to use. If the bentonite was not to be used right away, silos can be used for its proper dry storage. Dry weather will make installation more effective and efficient in order to achieve a proper mix, laying, and subsequent compaction.

Bentonite was selected to satisfy the requirement to best match the permeability of the bottom admix layer. Bentonite in some layers exposed to drying cycles may dessicate and crack and yield poor liners by themselves. The admix will work best since its a mixture and serves as a base for our other design layers. High grades of "Bentonite" are available in economically recoverable quantities in Wyoming and to a lesser extent in South Dakota and Montana. We selected Wyoming Bentonite which normally consists of high percentages of sodium montmorillonite, feldspar, quartz, and calcite. Bentonite's unique qualities are obtained from the sodium montmorillonite and they include:

- o An ability to expand and contract as water is absorbed and expelled with expansion and contraction occurring an infinite number of times.
- o An ability to expand 10^{-20} times its original volume or absorb up to five times its weight of water.
- o Totally inorganic, so it does not break down with time and a thickness of 3/16 to 3/8 inch has a hydraulic conductivity of 1×10^{-10} cm/sec.

The above characteristics are unique to high grade sodium bentonites as we selected from the Wyoming Distributor, Black Hills Bentonite. They can not be obtained by calcium bentonites or "beneficiated" calcium bentonites. Chemical composition of sodium is mostly SiO_2 with critical components being sodium oxide(Na_2O), Lime(CaO), and water(H_2O). The most active or highest quality montmorillonites are: greater than 2.0% Na_2O , less than 1.0% CaO and five to ten percent water (processed material). The virtue of clay materials is that they carry negative charges on their surfaces which will absorb positive charges such as adding water. Montmorillonite measures 360 to 500×10^{20} (number of positive charges absorbed per 100 gm soil). The high grade of bentonite obtained for our cover design should provide exceptional hydration of its clay particles with the available moisture when it is installed. This hydration will also hold true if for some reason there is a water protrusion through the top layers. The bentonite's great expansion will remedy the protrusion by resealing the barrier above.

The Primary Cover Design required 2000 cubic yards plus an additional 15% due to compaction, wastage, and to conservatively satisfy the project's requirements. The total needed was, therefore, 2300 cubic yards or 62,100 cubic feet. Average weight for "Black Hill's Gel" is 60-64 lbs/cubic foot. A 15% increase was a conservative approach to ensure an average weight of 62 lbs/cubic foot was used to avoid further excess. This output, a total of 3,726,000 lbs or 1925 tons was required.

The "Black Hills Gel" was selected and fit the high specifications called for the bottom liner's bentonite used in the Admix Layer. Golder Associates of Redmond, WA wrote the specifications in Document WHC-S-045 Rev 2, Part2, sec 2-2. These specifications are very high and are subject to the type of testing carried out on the product. Black Hills Gel was selected since it satisfied these specifications but was for a less expensive alternate, Black Hills Bond, would be adequate because it was already used in 1990 in four of Hanford's Water Containment Ponds. However, due to the size of the project, the price for both products was quoted the same, therefore Black Hills Gel was selected and has a free swell of 25ml per 2 grams. Bottom liner specifications from the Golder Associates of Redmond, WA are:

Material meeting American Petroleum Institute(API), Specification 13A, Section 4, with minimum yield of 91 barrels. Free swell of 25 ml/2 grams or greater. Products approved by COTR.

The minimum of 91 barrels is comparable to minimum viscosity(i.e. 30 weight oil) yielded per ton bentonite. 22.25 lbs/42 gallon barrel equals 91; 16 lbs/42 gallon barrel equals 125. The selected product for our design is Black Hills Gel.

Black Hills Gel Description:

Polymer Extended Wyoming Sodium Bentonite. Recommended for oil well drilling, slurry trenching, pond sealing, and most engineering applications. Yield 91 barrels(minimum) of API fluid to one ton material. Should satisfy swell of 22-25ml/2 grams. Conforms to API specification 13A.

An alternate for this project or others is the Black Hills Bond.

Description: Unaltered Wyoming Sodium Bentonite. For use in sealing of fresh water ponds, lagoons, and landfills. Yield 75-80 barrels(minimum) of API fluid to one ton material. Should satisfy swell of 22ml/2 grams but testing is subject to a margin of error as in Golder Specification Requirements. Conforms to API specification 13A.

Black Hills Bentonite deals with material costs only and no longer quotes a delivered price to job sites as they did in a 1991 contract for the four Hanford Water Containment Lagoons. They did, however, provide the information and quotes to provide bulk bentonite to Iceing Lead Team Track, Pasco, Wa via Burlington Northern rail and transloading and trucking from Pasco to the job site. The minimum of 190,000 lbs/rail car is what the railroad is using which is roughly 20 railcars. The trucking from Pasco to the job site can be done by Gresham Transfer of Portland; dispatcher Rick Ulmer (503)255-7900 Ext. 130 or by transferring the railcars up through Hanford Sites closest rail line where they can be transloaded by Kaiser Engineering. The transloading done by Gresham Trucking can be auger or conveyor belt. The bentonite can be stored in silos for

later use or directly taken off trucks, mixed and used providing the weather is dry and the railcars can be taken off-line for a time. The transportation of the bentonite beyond Pasco, WA must be determined and negotiated by Westinghouse Hanford. Project Engineer, Eric Epenbeck at (509)376-8032 can help determine these logistics.

Black Hills Bentonite has supplied bentonite to CETC Corp. and also 6000 to 8000 tons for the Hanford Waste Water Containment Ponds in 1991. For that job, the bentonite was supplied to Western Environmental, sold to C.B. Timber Company. Kaiser Engineering supervised the job.

Product: "Black Hills Gel" Bentonite

Material Costs: \$32/ton x 1925 tons = \$ 61,600

Shipping Costs: Burlington Northern Railroad Freight from Mills, Wyoming to Iceing Lead Team Track at Pasco, WA. Minimum 955 tons, 190,000# per car, about 20 cars).

\$31.91/ton x 1925 tons = \$ 61,430

Bulk Extraction and Pneumatic Trucking from Pasco to Job Site, and dumped into silo prior to use: Done by Gresham Transfer of Portland, phone (503)255-7900.

\$16.20/ton x 1925 tons loaded = \$ 31,185

This value of \$16/ton is based on 40 miles travel one way from Pasco plus \$0.50 to \$0.60 per ton for every extra 20 miles. The mileage is roughly 47 miles so a rough value of \$16.20/ton for transloading and delivery to the site can be negotiated by

Hanford Westinghouse or Kaiser Engineering for Hanford.

The total shipping and material cost is \$154,215.

Installation Costs: Considered \$0 because the installation can be conducted by Kaiser Engineering at Hanford(Overhead Costs) using the Hanford's "Pug Mill" and front end loaders.

Primary Design Total Cost = \$377,000

SECONDARY DESIGN MATERIAL DESCRIPTIONS:

A GCL Replaces the Admix Layer:

The following materials or man-made layers for the Secondary Design are the same as used in the Primary Design except for the 12% bentonite included in the Admix layer will be replaced with a Man-made Geosynthetic Clay Liner (GCL) on top of a standard depth of soil allowing for a flat and stable installation of the GCL. The GCL consists of bentonite sandwiched between two layers of geotextiles. As in the Primary Design, the Man-made GCL for the Secondary Design is also based on 244,000 sq. ft of coverage including 15%

added for wastage. This provides a conservative estimate when applying a GCL liner. The GCL will be easier to install and provide other advantages over the Admix layer.

E.P.A. regulations for waste containment specify that lagoon/landfill liners be composed of heavy plastic membrane layer (HDPE) on top of a thick layer of compacted clay (3 feet minimum). Because a single sheet of Claymax liner exceeds this requirement, it has been specified and installed as "the clay liner" in several landfills in the United States and Europe.

If the GCL is to be lined directly below the HDPE and in combination with the HDPE for a high coefficient of friction, then the James Clem Corporation's Needle-Punched Claymax 500SP may be the best suited and can have a frictional ability. The geotextile surface of the Claymax 500SP will adhere in one direction with the frictional surface of the HDPE and thus provide slope stability. The Claymax can provide a strong continuous base layer but conform to limited differential settling of the cover, as is expected for our design. This is one great advantage a needle-punched GCL has over a compacted clay line; it allows for more minor subsidence without failure. The high permeability rates of the Claymax 500SP, its ability to contain high water contents, and the company's confirmation on the price made Claymax 500SP the number one choice for the GCL line. The comparison of the two top GCLs are in Appendix E. The second choice is also shown below.

If air pockets occur where the layers do not meet, then there is a high possibility of drying over a long period of time. This would cause dessication failure in a compacted clay line, however, the GCL products would be less likely to fail if the complete HDPE system is also intact over the long period of time.

General Information About Claymax 500SP Includes:

- o Claymax liner is the state-of-the-art geocomposite liner that ingeniously combines the durability of woven GCLs fabric with the impermeability of a pound-per-GCLs-foot of an inert mineral, sodium bentonite (montmorillonite).
- o The Claymax liner has an overall self-healing ability if ripped or punctured. In its hydrated (swollen) state, the clay will swell up providing tremendous impermeability and a great resistance to all chemicals. In a typical installation, the 1/4 inch Claymax liner sheet will swell 1/2-to-1 inch resulting in the equivalent permeability of 30 feet of compacted clay.
- o Installation of Claymax is extremely easy. (See video) Minimal equipment and labor is required and the existing Hanford construction firms can easily install the material themselves.
- o The Claymax 500SP is linearly stitch-bonded with GCLs yarn along the length of the GCL. The rows of stitching are spaced every 4 in. across the width of the GCL. The manufacturer claims that stitch-bonding increases the internal shear strength of the GCL.

A 4oz/sq yard upper, woven geotextile and a 4 oz /sq yard lower, woven, reinforced geotextile were used for the Claymax 500SP GCL.

- o The Claymax 500SP can be installed on slope angles greater than 3H:1V. It is GCLs to provide high shear strength and durability. The advantages of GCLs are:
 - 1) Increased internal shear strength for use on steeper slopes.
 - 2) Holds Bentonite in place during installation.
 - 3) Prevents delamination of geotextiles when Bentonite hydrates
 - 4) Provides inherent confining stress, which decreases permeability
 - 5) Provides enhanced field ruggedness and durability
- o A Claymax 500SP GCL is equivalent to 3 feet of clay or at $K=1 \times 10^{-7}$ cm/sec (Darcy's Law). GCLs, 500SP holds in greater slopes but .25/lb Linear ft Bentonite is required at seams. 500SP may hold in more Bentonite over periods of drying and hydrating due to stitching. Reseals itself over periods of hydration and drying. Claymax is impermeable to gas following hydration.
- o The manufacturer places approximately 1 lb/GCLs of an amended bentonite into each GCL. The clay is placed in a uniform layer of approximately 0.2 in. using the proprietary adhesive discussed before. The in-place clay typically has a water content of around 20%. This high water content supposedly reduces the amount of free bentonite dust that can interfere with the seaming process of an overlying geomembrane. The manufacturer claims that up to 2lb/sq.ft of bentonite can be placed into the GCL for specialty projects but 1lb/sq ft is adequate for this project.
- o The Claymax 500 SP GCL typically comes in rolls that are 13.5ft wide by 82 ft. long but custom size rolls can be ordered. Individual rolls can be unrolled, and overlapped at the site in order to form a continuous barrier. An overlap of 6 to 9 in. is recommended by the manufacturer. Guidelines are printed along the edge of each roll to help install each GCL with the correct amount of overlap. When hydrated, the rolls are said to self seal at the overlap due to bentonite oozing from one roll to the other.

Geosynthetic Clay Liner (GCL) Liner Directly Below HDPE Liner:

Product: "Claymax 500SP"

Company: James Clem Corporation

Plus adding .25 lb/sq. ft of bentonite added at overlapped seams. Cost is to be determined. There is approximately 17,200 linear feet along with two vents with the to be covered bentonite which is 2500 pounds. This is a nonconservative figure. Black Hills Bentonite can ship this amount in a large durable sack via truck or rail/truck to the Site. The Claymax Corp. may also supply the bentonite but the best source for quality and quantity is Black Hills Bentonite.

Material Costs: 244,00 sq ft x \$0.38 to .43/sq ft = \$92,720 to \$104,920
minus cost savings of creating Admix layer.

Cost is \$.32 to \$.37+ \$.06/sq ft shipping

Total Average Cost = \$ 99,000

Shipping Costs: Included into the Material Costs but quoted as \$0.06-0.08/sq ft

Installation Costs: Considered \$0 because the installation can be conducted by Kaiser Engineering at Hanford(Overhead Costs)

Alternative GCL Product:

Another very good GCL and one whose frictional coefficient may be higher than the Claymax 500SP is the CETCO "Bentomat SS GCL". The geotextile surface of the Bentomat SS will adhere to the frictional surface of the HDPE and thus provide strong slope stability. The Bentomat SS is very flexible and conforming to limited differential settling of the cover. This is one great advantage a GCL has over a compacted clay liner; it allows for more minor subsidence without failure. The comparison of the two Gcls is in Appendix E.

Geosynthetic Clay Liner (GCL) Liner Directly Below HDPE Liner:

Product: "Bentomat SS GCL"

Company: CETCO Corporation

Plus adding .25 lb/sq. ft of bentonite added at overlapped seams. See Claymax GCL.

Material Costs: 244,00 sq ft x \$0.38 to .43q ft = \$92,720 to \$104,920
minus cost savings of creating Admix layer.

Total Average Cost = \$ 99,000 but non confirmed by Distributing

Company.

Shipping Costs: Included into the Material Costs but quoted as \$0.06-0.08/sq ft

Installation Costs: Considered \$0 because the installation can be conducted by Kaiser Engineering at Hanford(Overhead Costs)

Environmental Monitoring of the Site:

Groundwater monitoring shall be in accordance to Federal and State regulations(EPA/RCRA 265.92 AND .93). Information about location and number of wells is shown as of 1987 in Appendix D. Additional wells have been included and Westinghouse Hanford informed our design team that this customer requirement has been currently satisfied. Additional information about location, specific well construction and water tables as well as surface waters are shown in Appendix D.

The requirements for the use and location of monitoring wells applies to both the bottom liner and top cover liner designs. The top cover design will consider the water running off the top to be natural precipitation nonpolluted by runoff from the cover. This is then considered "clean" water and contamination from the waste site's cover design should not contaminate the ground water quality.

CONCLUSIONS

CONCLUSIONS SECTION

PRIMARY AND SECONDARY DESIGN'S LINER MATERIAL COSTS

PRIMARY DESIGN MATERIAL COSTS:

The following materials were those that could not be directly obtained from the surrounding vicinity of the job site. Man-made layers as well as bentonite for the bottom Admix layer are shown below. Man-made layers for the Primary Design were based on 244,000 sq. ft of coverage including 15% which was added for installation wastage. This 15% wastage value provides conservative estimates when applying a liner product. Any excess material not used in the laying of the High Density Polyethylene Liners may possibly be negotiated for return to the on-site installation crew. Most liner installation allows 10-15% for wastage so these figures are accurate estimates. The general names of the liner material along with the specific product name is below and shown in the order of the design from a top to bottom approach. The costs include installation, shipping, and other transportation costs. Details of specific liners are discussed in more detail in Appendix C.

Woven Slit Film For Separating Top Soil Layer and Rock Drainage Layer

Product: "200ST" Stabilization Slit Film (polypropylene geotextile) Cost- \$10,000

Company: Synthetic Industries supplied by Northwest Linings & Geotextile Products, Inc., Kent, WA

Geotextile/Fabric Net for Separating Rock Drainage Layer and HDPE Liner

Product: "Fabri-Net(Gundnet/Geotextile) Composite", (2 sides Cost- \$109,800

Geotextile Woven Polyethylene Composite surrounding Fabri-Net XL-14)

Company: Gundle Lining Systems Inc.

High Density Polyethylene(HDPE) Liner Separating Gundnet Geotextile and Admix Layer

Product: "Friction Seal 60 mil HD 2 Sides" Cost- \$103,000

Company: National Seal Company

Bentonite for Bottom Admix Layer(12% ratio of bentonite to site soil))

Product: "Black Hill's Gel" Cost- \$154,215

Company: Black Hill's Bentonite Company

Cost is dependent on transportation.

Primary Design Total Cost = \$377,000

SECONDARY DESIGN MATERIAL COSTS:

The following materials or man-made layers for the Secondary Design are the same used in the Primary Design. The exception is the Secondary Design has replaced the 12% bentonite included in the Admix layer with a man-made Geosynthetic Clay Liner (GCL). This GCL is still laid upon a standard depth(approx. 12 inches compacted) of soil allowing for a flat and stable installation of the GCL. The GCL consists of bentonite sandwiched between two layers of geotextiles. As in the Primary Design, the man-made GCL for the Secondary Design was also based on 244,000 sq. ft of coverage which included 15% added for wastage. This provided a conservative estimate when applying a GCL liner. The GCL will be easier to install and provide other advantages over the Admix layer. The costs include installation, shipping, and other transportation costs. Details of the specific GCL liners are discussed in more detail in Appendix C.

Primary Layers (Same as Primary Design) Cost- \$222,800

Geosynthetic Clay Liner (GCL) Liner Directly Below HDPE Liner

Product: "Claymax 500SP GCL" Cost- \$ 99,000

Company: James Clem Corporation

Plus adding .25 lb/sq. ft of bentonite added at overlapped seams. Cost- \$ **

6 inch overlap equals .25lb actual per 2 feet of liner interface so the estimated bentonite required is to cover 17,200 linear feet plus two vents or 2500 pounds which is a nonconservative figure). ** Costs to be negotiated and contracted by Hanford Corp. See Material Descriptions section for further information.

Note: Minus cost of Admix Layer Preparation and installation.

Secondary Design Total Cost = \$321,800

General Conclusions:

- o A layering system has been chosen to meet both the RCRA and DOE regulations.
- o Combination of soils and geosynthetic products have been used together in the layering system.
- o Erosion control can be accomplished through minimum slopes of 3 Horizontal to 1 Vertical (3H:1V) and a 3 to 5 percent grade is used for the remainder of the cover.
- o Cover meets or exceeds RCRA and DOE regulations. Cover meets all of Westinghouse Hanford design criterion.
- o Combination of Geosynthetics and indigenous soils in a layered system best suits design criterion.

- o Liquid migration and possible gas percolation are minimized due to the configuration.
- o Wind erosion will be minimized through the placing of indigenous plants on the cover.
- o A 30 year life span with year-round use is achieved through the design configuration.
- o Maximizing of waste capacity is achieved through cover design.
- o All liner material products can be properly installed per the installation instructions from the contractors and distributing companies.
- o The HDPE liners must be installed by a specialized company in which double extrusion welding is a normal practice for the company. The company should have had installed at least one million square feet of a HDPE liner.
- o Due to the strict regulations outlined in Subtitles C and D of the Resource Conservation and Recovery Act (RCRA), a landfill operator/owner must do everything possible to protect the groundwater in the region surrounding the landfill. For this reason, landfills are presently designed to reduce, or eliminate, the possibility of leakage to the surrounding soils and groundwater.
- o The hydraulic conductivity of the compacted clay liner or Admix layer must be less than or equal to the hydraulic conductivity of the soil component of the bottom liner system for a Subtitle C landfill (Title 40, Code of Federal Regulations (CFR), Part 264.310(a)(5), which itself must be less than or equal to 1×10^{-7} cm/s (Title 40, CFR, Part 264.301(c)).
- o Unless our waste is properly treated prior to disposal, final cover will undergo distortional stresses due to active decomposition of waste or settling which is more important in our case.
- o The cover soil is made up of two components. The upper component is the vegetation layer. As the name implies, the purpose of this layer is to promote vegetative growth. The vegetation should be indigenous, must be able to survive extremes in temperature and moisture, have a shallow root system, and require a low level of maintenance. This upper component must also promote runoff and resist erosion from a major storm.
- o The lower component is known as the protection layer. The purpose of this layer is to store water for the overlying vegetative layer, provide a soil backup to any long term, deep erosional losses, and to provide a physical barrier to prevent any plants or animals from coming into contact with the waste below. The protection layer should also insulate the underlying hydraulic barrier from damage to wet/dry or freeze/thaw cycles.
- o In arid regions where indigenous vegetation is not present, the cover soil is typically just made up of the protection layer. A mixture of native soils and cobbles can provide the

necessary protection. Not only do cobbles provide a physical barrier, they are also more resistant to the weathering due to wind erosion and thermal fluctuations. As cobbles are more resistant to the erosional damage due to heavy rainfall, steeper cover slopes can be employed. However, cobbles will allow water from rainfall or melted snow to percolate downward and do not promote evaporation of water back to the atmosphere.

Drainage Layer

- o The purpose of the drainage layer is to quickly drain off any water passing through the overlying cover soil. Infiltrating water should not be allowed to pond on the underlying hydraulic barrier which could result in flow to the waste below. The drainage layer is composed of a freely draining, coarse-grained material such as gravel and a synthetic material such as a geonet or a geotextile underlying it.
- o Drainage occurs by gravity flow to a toe drain along the edge of the final cover. The toe drain must be able to handle the discharge from the peak outflow of severe storm. If not properly designed, water pressure can build up at the toe leading to infiltration into the waste below, or perhaps worse, erosion of the cover soil along the edge of the cover.
- o In arid regions, where rainfall is sporadic and minimal, and the evapotranspiration rate is high, the drainage layer may not be fully utilized or even necessary.

RECOMMENDATIONS

RECOMMENDATIONS SECTION

The preceding sections discussed what the components of the final cover design were and the various functions of each layer making up the final cover. The following discusses additional information that may not have been covered.

COVER INTERFERENCE WITH EXISTING STRUCTURES:

As mentioned earlier, the installation of the final cover extended over part of the existing service road and the final cover configuration with the new road is shown on Figure 9.

A model of the W-025 site was constructed by Design Team CEE 94.6 and included existing structures and the proposed final cover. Upon completion of the model, it was discovered that the final cover design encroached upon existing structures: a 10,000 gallon leachate tank and mechanical building.

The cover dimensions have been minimized to a point where compromise is non-negotiable. To decrease the area enclosed by the final cover or change the configuration of the cover would ultimately compromise the cover's integrity thus reducing waste capacity.

Two solutions are suggested; construct a retaining wall or move the existing installations. The latter is the suggested solution. To construct the proposed retaining wall would be extremely costly, perhaps more so than moving the tank and building structures (Refer to Figure 10, titled, "Proposed Retaining Wall Design". Due to the late discovery of this interference, a cost analysis of this problem is unavailable.

LONG-TERM MAINTENANCE:

Maintenance of the final cover's structure should be continuous to assure long-term structural and functional integrity. All created holes or differential settlement shall be filled to a level equivalent to the slope angles declared for the final cover. Inspection of serious damage should be directed to Hanford Engineering for determination of further maintenance procedures. All repaired or filled areas should be repaired with equivalent liner materials as they are discussed in this report. To maintain proper vegetation growth, cow manure may be obtained cost-free from local cow feed lots.

FINAL COVER CONFIGURATION W/
RECONSTRUCTED ROAD

FIGURE 9 - FINAL COVER CONFIGURATION WITH RECONSTRUCTED ROAD

23rd STREET

RETAINING WALL

FIGURE 10 - PROPOSED RETAINING WALL DESIGN

RECOMMENDATIONS - PROPOSED SYNTHETIC LINER MATERIALS AND BENTONITE FOR ADMIX

PRIMARY DESIGN MATERIALS:

The following materials were those that could not be directly obtained from the surrounding vicinity of the job site. Man-made layers as well as bentonite for the bottom Admix layer are shown below. Man-made layers for the Primary Design were based on 244,000 sq. ft of coverage including 15% which was added for installation wastage. This 15% wastage value provides conservative estimates when applying a liner product. Any excess material not used in the laying of the High Density Polyethylene Liners may possibly be negotiated for return to the on-site installation crew. Most liner installation allows 10-15% for wastage so these figures are accurate estimates. The general names of the liner material along with the specific product name is below and shown in the order of the design from a top to bottom approach.

Woven Slit Film For Separating Top Soil Layer and Rock Drainage Layer

Product: "200ST" Stabilization Slit Film (polypropylene geotextile) Cost- \$10,000
Company: Synthetic Industries supplied by Northwest Linings &
Geotextile Products, Inc., Kent, WA

Geotextile/Fabric Net for Separating Rock Drainage Layer and HDPE Liner

Product: "Fabri-Net(Gundnet/Geotextile) Composite", (2 sides Cost- \$109,800
Geotextile Woven Polyethylene Composite surrounding
Fabri-Net XL-14)
Company: Gundle Lining Systems Inc.

High Density Polyethylene(HDPE) Liner Separating Gundnet Geotextile and Admix Layer

Product: "Friction Seal 60 mil HD 2 Sides" Cost- \$103,000
Company: National Seal Company

Bentonite for Bottom Admix Layer(12% ratio of bentonite to site soil))

Product: "Black Hill's Gel" Cost- \$154,215
Company: Black Hill's Bentonite Company
Cost is dependent on transportation.

Primary Design Total Cost = \$377,000

SECONDARY DESIGN MATERIALS:

The following materials or man-made layers for the Secondary Design were the same used in the Primary Design. The exception in the Secondary Design is replacing the 12% bentonite included in the Admix layer with a man-made Geosynthetic Clay Liner (GCL). This GCL is still laid upon a standard depth(approx. 12 inches compacted) of soil allowing for a flat and stable installation of the GCL. The GCL consists of bentonite sandwiched

between two layers of geotextiles. As in the Primary Design, the man-made GCL for the Secondary Design was also based on 244,000 sq. ft of coverage which includes 15% added for wastage. This provided a conservative estimate when applying a GCL liner. The GCL will be easier to install and provide other advantages over the Admix layer. The costs include installation, shipping, and other transportation costs. Details of the specific GCL liner are discussed in more detail in Appendix C.

Primary Layers (Same as Primary Design) , Cost- \$222,800

Geosynthetic Clay Liner (GCL) Liner Directly Below HDPE Liner

Product: "Claymax 500SP GCL" Cost- \$103,000

Company: CETCO Corporation

Plus adding .25 lb/sq. ft of bentonite added at overlapped seams. Cost- \$ **

6 inch overlap equals .25lb actual per 2 feet of liner interface so the estimated bentonite required is to cover 17,200 linear feet plus two vents or 2500 pounds bentonite(nonconservative figure). ** Costs to be negotiated and contracted by Hanford Corp. See Material Descriptions section for further information.

Note: Minus cost of Admix Layer Preparation and installation.

Secondary Design Total Cost = \$321,800

GENERAL RECOMMENDATIONS:

- o Waste cell compaction is critical in order to maintain cover integrity. A quality assurance program should be implemented during loading of the landfill to ensure a uniform compaction.
- o The admix layer will be rolled with a steel drum to ensure a smooth surface prior to construction of the high density polyethylene liner.
- o All debris, such as sharp stones, roots, or anything that could be considered a hazard to the high density polyethylene liner will be removed prior to the construction.
- o The National Seal Company's Friction Flex 60 HD (HDPE) must provide adequate texture finish which is as deep and varied as possible and cover the entire base HDPE to ensure irregularity and proper coefficient of friction for both the drainage geonet, "Fabri-Net", and the GCL is the Secondary Design is used.
- o The compacted soil/bentonite layer should include materials taken from the McGee Ranch Borrow Site due their natural high levels of clay.
- o All subsequent soil or material needed should be obtained from on site, or from the two referenced borrow sites (McGee Ranch, Area A) through separation or screening. We feel the

- o All liner materials recommended by our design team should have Installation Procedures, Material Specifications, and bid costs obtained from the products' company or a recommended distributor. These step by step installation procedures will allow the operations section at the Hanford Corporation to do the installation on all liner material except the HDPE liner. When all installation procedures are obtained, a project engineer can properly schedule the job.
- o All installation of overlapped seams should attempt to have all long pieces left for the steeper slopes on the sides.
- o The Woven Slit Film, Geonet "Fabri-Net", and GCL for the secondary design has relatively easy procedures for installation as long as proper interfaces occur between the layers and the seaming process is according to spec. The natural layers shall be done according to the type of layers lying below. One example would be the compaction of the rip-rap drainage area on top of the "Fabri-Net" must be done without penetration into the Fabri-Net causing harm to the HDPE and level at its top to allow the woven slit film to be consistent and without shear stresses imposed on it.
- o The NSC Friction Seal 60 Mil HD (HDPE) liner shall be installed by a specialized installation team from NSC or a distributor. One distributor is Northwest Liners and Geotextiles Inc. in Kent, Washington. The company winning the installation contract must be responsible for installation and overseen by Hanford to assure proper installation around the vents, and/ or top of the GCL if the Secondary Design is used.

Fabri-Net Geonet Product:

- o Some general recommendations are mentioned below, with specific recommendations concerning the "Fabri-Net" which is very similar to the installation of the woven slit film.
- o The Geonet "Fabri-Net" product is adequate for normal loading on the cover but increased loading may prompt further analysis. Further analysis to either use the Geonet "Fabric-Net" product as it is sold with two 6 oz sides of woven geotextile with a replacement top layer of a non-woven polyethylene. This non-woven polyethylene geotextile could be the Synthetic Industries 701 product or a thicker product which would assure more puncture strength than that of the Fabri-Net geotextile.

These recommendations describe a high density polyethylene (HDPE) drainage net-geotextile geocomposite. The "Fabri-Net" drainage net shall contain stabilizers to prevent ultraviolet light degradation. The geocomposite shall be manufactured by heat bonding the geotextile to the Gundnet XL-14 on both sides. No burn through geotextiles shall be permitted. The manufacturer shall submit samples of the "Fabri-Net" geotextile to the engineer with a complete set of specifications for approval.

Installation Steps:

Care shall be taken to keep the geocomposite clean and free from debris prior to installation. If geocomposite is not free of soil and debris before installation, it shall be cleaned by the contractor just prior to installation. On slopes, adjacent rolls shall be overlapped approximately 2-4 inches and secured by plastic ties approximately every

five (5) feet along the roll length. Plastic ties shall be white or another bright color for easy inspection. Metallic ties shall not be allowed. The geotextile will then be either overlapped, sewn, or heat tacked per the manufacturers recommendation. The geocomposite shall not be welded to geomembranes. In the corners of the side slopes, where overlaps between rolls of geocomposite are staggered, an extra layer of geocomposite shall be installed from the top to the bottom of the slope.

The geocomposite shall be placed on all side slopes as shown on the contract drawings. The geocomposite shall be secured in the anchor trench and then rolled down the slope over the "textured" HDPE in such a manner as to continually keep the geocomposite in tension. If necessary, the geocomposite shall be positioned by hand after being unrolled to minimize wrinkles. The geocomposite can not be placed in the horizontal direction (i.e., across the slope).

In the presence of wind, all geocomposite rolls in place shall be weighted with sandbags or the equivalent. Such sandbags shall be installed during placement and shall remain until replaced with cover material. Contractors shall place all cover materials in such a manner as to ensure the geocomposite and underlying materials are not damaged.

- o The Admix layer was previously covered in the results section. The use of a Claymax 500SP GCL is mentioned in greater detail even though its primary installation information can be obtained from a company video and requested installation procedures.
- o Both total and differential settlement can be minimized within a municipal solid waste landfill in several ways. As the solid waste is placed in the landfill, it can be dynamically compacted by repeatability dropping a large, flat weight onto the waste. Not only will this reduce future settlement, but it will also increase the amount of space in the landfill available for waste.
- o It has been observed that differential settlements tend to be the highest along the side slopes of a landfill. The solid waste along the side slopes is initially less dense than the surrounding waste as compaction becomes more difficult at the edges. This less dense waste will then likely undergo larger post closure settlement. In addition, the thickness of the waste along the side slopes is lower, resulting in a lower net stiffness. They recommend putting on a generous daily soil cover along the side slopes to increase the amount of operational settlement, and to increase the overall stiffness of the waste. (Morris and Woods, 1990)
- o Wastes of variable stiffness should not be placed next to each other (i.e. a cell full of barrels next to a cell full of yard wastes). As the softer wastes settle, the stiffer wastes will remain rigid, leading to differential settlement.

Bentonite used for Admix

- o In bulk shipments, prior to stockpiling of bentonite material, storage sites shall be cleared and leveled. All bentonite material stockpiled shall be adequately protected to prevent erosion and water damage to bulk or bag product that may alter the quality of the material. If more than one grade of material is being utilized, then each material must be stockpiled separately and materials from different sources shall be segregated. For unusual storage conditions, consult the material supplier.
- o Liner installation shall not begin until a proper subbase has been prepared to accept the bentonite liner. Unless otherwise required by the contract specifications and drawings, the prepared surface shall be free from loose earth, fully exposed rocks larger than 1/2 inch in diameter, rubble and other foreign matter. The subgrade shall be uniformly compacted to a minimum of 90% modified proctor density (ASTM D1557), to ensure against settlement and rutting under wheel loads and shall be smoothed with a smooth drum or vibratory roller. Field Density tests shall be made using either ASTM D2922 or D1556 at a frequency of one per acre to verify the compaction of the subgrade.

Many recommendations concerning the installation of the Secondary Cover Design includes a Geosynthetic Clay Liner, called Claymax 500SP. Since it is the Secondary Design and the recommendations are lengthy, Claymax recommendations are contained in the first section of Appendix E.

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REFERENCES:

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- 6) Functional Design Criteria - Interim RMW Disposal Facility, Project W-025 Nov., 1987, Issued By Westinghouse Hanford Company2) Golder Associates, Inc. 11-2-91,; Document # SD-W025-FDC-001, Rev1 (Specification of Life Span).
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- 13) Northwest Linings and Geotextile Products, Inc, 20017 89th Avenue South, Kent WA 98031, Phone (206) 872-0244, Fax (206) 872-0244, Rick W. Newton, Sales Manager.
- 14) Gundle Lining systems Inc, "Fabri-Net", 19103 Gundle Road, Houston, Texas 77073, Phone (713) 443-8565 or 1-800-435-2008, Fax (713) 875-6010.
- 15) Synthetic Industries, "Woven Slit Film 200ST", 4019 Industry Drive, Chattonooga, TN 37416, Phone 1-800-621-044, Fax (615) 899-7619. (A distributor is Northwest Linings, Kent, WA).
- 16) James Clem Corporation, "Claymax 500SP GCL", Regional Manager, Thomas F. Hauch, (415)578-0295, 1800-220-2536.

- 17) Black Hills Bentonite Company, "Black Hills Gel"; P.O. Box 9, Mills, Wyoming 82644, Pat Williams on Pricing, Robert Parsons on Technical Product Information. (307)265-3740, Fax (307) 235-8511 Address: 55 S. Salt Creek HWY, Casper, WY.
- 18) Golder Associates Inc., 1993b, Construction Quality Assurance Plan for Project W-025, Radioactive Mixed Waste (RMW) Landfill Disposal Facility-Non-Drag-Off, WHC-SD-W025-Pln-001, Rev. 3, U.S. Department of Energy, Richland, Washington.
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- 28) Colloid Environmental Technologies Company (CETCO), "Bentonite and Bentomat SS", 1500 West Shure Drive, Arlington Heights, Illinois, 60004-7803, Phone (708) 392-5800, Fax (708) 506-6150, Robert Trauge, Technical Services.
- 29) SLT North America, Inc., SLT Friction Seal, 15711 Hardy Road #3B, Houston, TX 77068, (713)445-1771, Fax (713)591-2219; 6 Venture #100, Irvine, CA 92718 (714)727-0486, Fax(714)753-1399; John Davis Sales

APPENDICES

APPENDIX A:
SCOPE OF WORK

APPENDIX A:

Scope of Work:

The scope of work as received from WHC has been summarized below.

The scope, for implementing the design of an Environmentally Compliant Final Closure Cover of a Hazardous Mixed Waste Disposal Facility at Hanford, included examination of requirements for erosion control/prevention/mitigation; runoff control; maintenance requirements; repair of disturbances to maintain cover integrity for its required life span, and cost estimates for materials and their installation. The final closure cover must meet or exceed all applicable state and federal laws and regulations.

The final report shall include at least the following items:

- o Executive summary and Introduction.
- o Citations for all criteria sources.
- o Criteria used to evaluate alternatives including a narrative description of the process and the rational for selection of the preferred alternative.
- o Development of the preferred alternative to a level of detail from which construction specifications, and acceptance testing procedures can be developed.
- o Results of market surveys for material availability.
- o Functional description(s) of the rational for the features for the cover.
- o References
- o Bibliography

The draft of the final report shall be submitted for review and comment by representatives of the buyer. Ten(10) copies of the draft will be allowed for representatives of the buyer to review and comment on the draft report. Comments will be reviewed with the seller and comment resolution achieved.

Delivery of five (5) copies and one (1) camera ready master of the final report with comments incorporated is requested by 6/30/94.

APPENDIX B
"RESUMES OF PROJECT ENGINEERS"

OBJECTIVE

To obtain an entry level position in the Civil Engineering Field.

EDUCATION

Seattle University,

Bachelor of Science, Civil Engineering, December 1994
Structures and Environmental Concentration
GPA = 3.30

Edmonds Community College

Associate of Arts and Sciences Degree, June 1992

RELATED COURSEWORK

- *Fluid Mechanics / Applied Hydraulics
- *Applied Geology / Soil Mechanics
- *Groundwater / Water Resources
- *Strength of Materials / Structural Analysis
- *Environmental Engineering
- *Critical Thinking and Writing
- *Microsoft Excel, Microsoft Word, Microsoft Windows

EXPERIENCE

Senior Design Project, 1993-1994

Co-designer of a permanent environmentally final closure cover for a low level mixed hazardous waste disposal site. The project is sponsored by Westinghouse Corporation in Richland, Washington.

Laboratory Instructor, Spring 1993

Laboratory Instructor for Surveying and Engineering Measurements class, required to demonstrate to students the operation and proper handling of all surveying equipment.

Fred Meyer Corporation, 1991-1993

Grocery Worker and Member of the UFCW Union, stocked shelves, built displays, assessed inventory, prepared orders, provided customer service.

Denny's Corporation, 1988-1991

Waiter, provided customer service, arranged banquets, managed.

Ornamental Stone Construction, 1985-1987

Craftsman, built and designed concrete exposed aggregate merchandise.

ACTIVITIES AND HONORS

- Winner of the SU/UW Annual Student ASCE Paper Competition.
- American Society of Civil Engineers student member
- Dean's List - Fall 1993, Winter 1994

RESUME

Steven Nicholas
14814 89th St. Ct. KPN
Gig Harbor, Washington 98329
(206) 884-9317

EXPERIENCE SUMMARY: Production liaison engineer, construction supervisor with commercial, residential and modular construction experience, journeyman carpenter, office manager

MAJOR CAREER CHANGE:

1989 to present Civil engineering graduate
Seattle University, Seattle, Washington

Co-designer of environmentally compliant final cover for low level radioactive waste as graduation project.

EMPLOYMENT HISTORY:

1976 to 1989 Superintendent, foreman, journeyman carpenter and production engineer
Carpenter's Local 470 Tacoma, Washington

Responsible and accountable for project construction and timely completion of projects. Managing the dynamics of residential and commercial construction on site. Responsibilities included but were not limited to construction compliance to blueprint specification, liaison work between engineers and craft personnel, craft personal supervision and assisting in development of production isometric drawings of HVAC, electrical, piping, and structural disciplines.

1972 to 1976 Office manager, dispatcher, and warehouseman
Peter's Office Supply Portland, Oregon

Responsible for manpower schedules, productivity, warehouse inventory, and dispatching of delivery trucks.

EDUCATION: Bachelor of Science Degree in Civil Engineering
Seattle University, Seattle, Washington 1992-1994

Associates in Arts and Science
Tacoma Community College 1989-92

Certificate of Carpentry
L. H. Bates Technical Institute 1976-80

Sociology Major
Mt. Hood Community College 1970-72

SPECIAL AWARDS: 1st place winner of design
presentation for Civil Department
Seattle University

Tacoma Community College Outstanding Student
Achievement Award

Dean's List, Winter quarter, 1994
Seattle University

Association of Mechanical Engineering Award for
design excellence as sophomore

**COMMUNITY
SERVICE:** Assisted in construction of my children's
Elementary school covered play area.

Assisted children's Paleontology project.

Assitant Coach in local Little League Organization.

REFERENCES UPON REQUEST

MARK A. STOCKTON

19503 S.E. 241st Place
Kent, WA 98042
Phone: (206) 432-8916 Home
965-7093 Work

**CAREER
OBJECTIVE**

To secure an Environmental Engineering position utilizing my skills while pursuing a respectable expertise level in the field.

EDUCATION

B.S. Civil Engineering with Specialization in Environmental Engineering
June 1994, Seattle University, Seattle, Washington GPA-3.76/4.0

B.S. Industrial Operations Management(Eq. Industrial Engineering)
Aug. 1984, University of Wyoming, Laramie, Wyoming.
Expired Secret Classification (CNWDI) Boeing Company.

EXPERIENCE

4/86 to Present

CAD/CAM Systems Analyst - Boeing Commercial Airplane Company and Boeing Computer Services Division, Seattle, WA.

Responsible for CATIA (3D CAD/CAM) Numerical Control(NC) Software testing/user consultation CATIA NC processing of CAD/CAM generated digital data with subsequent part machining(mill, lathe). Consulted 1500 NC users on functionality, new applications, provided training/demonstrations, designed test plans/models, developed automatic regression testing, identified software problems while identifying user impact, satisfaction of user and system requirements and/or feasible work arounds. One of three consultants pretesting and implementing this software company-wide. Documented Requirements, User Guides, Test Plans, Reports. Dealt with interface applications along with NC simulation using Robotics package.

9/93 to 6/94

Civil/Environmental Staff Engr. - Seattle University Civil Engr. Senior Design Project contracted with Westinghouse Hanford Company; Seattle, WA.

Senior Design Project in group of three to submit proposal(Dec. '93) and final Report by June 1994. Design of an Environmentally Compliant Final Closure Cover for a Hanford Radioactive Mixed Waste Disposal Facility. Alternative analysis to a level of detail from which construction drawings, bid packages, and specs can be developed.

4/86 to 5/86

CAD Systems Analyst - Boeing Commercial Airplane Company, Seattle, WA.

Transferred to Computing Development Organization. Worked on CATIA (3D CAD/CAM) to create Optical drawings for Laser Alignment Leveling System Project for Tooling Structures while analyzing technical design changes and installs. Created Tooling Details for a CATIA library. Worked with computerized mechanism movements and published Kinematics Training Work Book.

2/85 to 4/86

Systems Engineer- Boeing Aerospace Company, Seattle, WA.

Worked within Systems Requirements Analysis group(specifically Physical Security Systems Engineering) of the Hard Mobile Basing(HMB) program. Conducted trade studies on operational concepts, active and passive delay technology, threat and vulnerability analysis, prepared Security Response Force and Vehicle study by research and modeling. Prepared and documented requirements and proposal for Air Force. Used CIMLINC CAD system for functional flows, trade studies.

5/79 to 2/85

Other Experience Includes:

- Heavy Equipment Operator chip sealing Wyoming and Colorado roadways, 5 ms.
- Surveyor for a Bentonite Mining company while supervising a subordinate, 3 mns
- Bricklayer/Hod Carrier/Cement Mixer in SE Wyoming, Forklift, Scaffolding, 3 mns

- Front End Loader Operator/Maintenance worker for a cement company, 3 months
- Other: Carpenter Helper(1 Mn), Laborer, Store Clerk/Inventory(3 Years), Sawmill-Stacker, Maintenance of Kiln Pipes and Boiler(4 mns)

References; Awards; Work Reviews/Operating Plans for 9 year Work History Upon Request.

APPENDIX C

**LINER MATERIAL DECISION MATRICES
AND
MATERIAL SPECIFICATIONS**

APPENDIX C

Decision Matrix for Geomebrane Liners

A one peice decision matrix was used to assess all liners together but then the three Dicsion Matrixes. They are broken up as follows:

Matrix #1:

- o Woven and Non-woven Geotextiles (WG or NWG)

Matrix #2:

- o High Density Polyethylene(HDPE) Membranes, (GMs=Geomembranes)

Matrix #3:

- o Geosynthethic Clay Liners(GCLs)
- o Compacted CLay Liners (CCLs) Note: These are not recommended by themselves or exposed, can be effieicntly used in a composite layer.

See next page.....

LINER DECISION MATRIX/INFORMATION LOG:

Name of Company	WOVEN/NONWOVEN GEOTEXTILE LINERS						
	NAT'L SEAL	NAT'L SEAL	NAT'L SEAL	GUNDLE COMP	SLT COMP	SLT COMP	TREVIRA
	TEX NET	TEX NET	TEX NET	FABRI-NET GEO-	GS228	GS228/1120	GEOTEXTILE
	NO SIDES 3000	ONE SIDE 3000	TWO SIDES 3000	TEXTILE 2 SIDES	NET ONLY	2 SIDES FABRIC	
Installation Expertise RQD Easy-3 Fair-2 Hard-1	3 HC	3 HC	3 HC	3 HC	3 HC	3 HC	3 HC
Chemical Compatibility Probs. Chem None=2 Yes=1	2.2	2.3	2.4	2.4	2.2	2.4	2.4
Capable of Vertical Venting	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Capable of Horiz. Venting	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Meets WA State Requirement	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Permeability (Hyd. Cond.)	Higher	High	High	High	Higher	High	Moderate
Effective Gas Barrier (Hydrated=1, Nonhydr=2)	No 0	No 0.1	No 0.3	No 0.3	No 0	No 0.3	No .02
Recommended Slope Angles:			+	+		+	+
Does it Satisfy 3H:1V?	2.5	2.6	2.7	2.7	2.5	2.7	2.0
Resist to Frost Upheaval	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Climate Adaptability **	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Burrowing Animal Protection	1.2	1.4	1.6	1.6	1.2	1.6	1.2
Settlement Deterioration Protect.	2.0	2.2	2.4	2.4	2.0	2.4	1.7
Sun/UV Resistant Yes-2 No-1	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cover Erosion Functionality	2.3	2.5	3.0	3.0	2.3	3.0	2.5
Puncture Vulnerability Def.	0.4	1.0	1.5	1.5	0.4	1.5	0.4
# of Layers Required	1 or 2	1 or 2	1 or 2	1 or 2	1 or 2	1 or 2	1 or 2
Fits What Alternative?	#1 or #2	#1 or #2	#1 or #2	#1 or #2	#1 or #2	#1 or #2	#1 or #2
Tech Advantages Yes=2	2.0	2.2	2.5	2.8	2.0	2.5	1.0
Tech Disadvantages Y=0 N=1	0.4	0.6	0.8	0.8	0.4	0.8	0.4
Use for Side Drainage**	0	0.3	0.6	0.6	0	0.6	0
Can Support Side Slope**	1.6	1.8	2.0	2.0	1.6	2.0	0.2
Materials Cost (\$per sq. ft)	.18	.30-.31	.45-.46	.45	.123	.275	N/A
Shipping Cost (\$per sq. ft)	0	0	0	0	.03	.03	N/A
Shipping Cost per truckload	0	0	0	0	\$2,800	\$2,800	N/A
Maintenance Cost/installed	- HC	- HC	- HC	- HC	- HC	- HC	- HC
Company Contracts**	3.0	3.0	3.0	3.0	3.0	3.0	2.8
Width of Rolls (feet)	7.5	-	-	14	-	-	15
Warranty Years	-	-	-	-	-	-	-
Length of Rolls (feet)	300	-	-	200 (80z.)	-	-	-
Total Rating	28.6	33.0	31.0	34.1	30.6	33.8	25.4
Additional Information:				Best Choice		Good	

**Good=3 Fair=2 Poor=1

HC=Hanford Company

TABLE A1 - DECISION MATRIX: WOVEN AND NONWOVEN GEOTEXTILES

HIGH DENSITY POLYETHYLENE (HDPE) LINERS

Name of Company			Installation Expertise RQD Easy-3 Fair-2 Hard-1			Chemical Compatibility Probs. Chem None=2 Yes=1			Capable of Vertical Venting			Capable of Horiz. Venting			Meets WA State Requirement			Permeability (Hyd. Cond.) Effective Gas Barrier			(Hydrated=1, Nonhydr=2) Recommended Slope Angles:			Does it Satisfy 3H:1V?			Resist to Frost Upheaval			Climate Adaptability **			Burrowing Animal Protection			Settlement Deterioration Protect			Surviv Resistant Yes-2 No-1			Cover Erosion Functionality			Puncture Vulnerability Det.			# of Layers Required			Fits What Alternative?			Tech Advantages Yes=2 Tech Disadvantages Y=0 N=1			Use for Side Drains **			Can Support Side Slope **			Materials Cost (\$per sq. ft.)			Shipping Cost (\$per sq. ft.)			Shipping Cost per truckload			Maintenance Cost/Installed			Company Contacts **			Width of Rolls (feet)			Warranty Years			Length of Rolls (feet)			Total Rating			Additional Information:																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
MATT SEAL 60 MIL HD 2 SIDES			2.8	2.2	2.5	Yes	Yes	Yes	Yes	2.0	+	3.0	2.8	2.9	3.0	3.0	3.2	2.8	2.0	2.0	2.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2

**Good=3 Fair=2 Poor=1
HC=Hanford Company

TABLE A2 - DECISION MATRIX: HIGH DENSITY POLYETHYLENE (HDPE) LINERS

LINER DECISION MATRIX/INFORMATION LOG:

Name of Company	GEOSYNTHETIC CLAY LINERS				COMPACT CLAY LINER	
	CLAYMAX	CLAYMAX	FSI COMP	CETCO CORP	BLACK HILLS BENTONITE	
	(GCL)200R	(GCL)500SP	BENTOFIX	BENTOMAT	12% CCL/ADMIX	12% CCL/ADMIX
			(GCL)	(GCL)	GEL	BOND TYPE
Installation Expertise RQD Easy-3 Fair-2 Hard-1	3 Includes Video/HC	3 Includes Video/HC	2.9 HC?	2.9 HC?	1.5 HC	1.5 HC
Chemical Compatibility Probs. Chem None=2 Yes=1	needs test 2	needs test 2~	2?	2?	1.8	1.8
Capable of Vertical Venting	Yes	Yes	Yes	Yes	Yes	Yes
Capable of Horiz. Venting	Yes	Yes	Yes	Yes	Yes	Yes
Meets WA State Requirement	Yes	Yes	Yes	Yes	Yes	Yes
Permeability (Hyd. Cond.)	5x10 ⁻⁹	5x10 ⁻⁹	<1x10 ⁻⁹	3-3.5x10 ⁻⁹	1x10 ⁻⁸	1x10 ⁻⁸
Effective Gas Barrier (Hydrated=1, Nonhydr=2)	Yes 1.5	Yes 1.5	Yes 1.5	Yes 1.5	Yes 1.8	Yes 1.8
Recommended Slope Angles:	3H:1V	>3H:1V	-	-	-	-
Does it Satisfy 3H:1V?	2.8	3.0	2.8	2.8	Max	Max
Resist to Frost Upheaval	3.0	3.0	3.0	3.0	-	-
Climate Adaptability **	3.0	3.0	3.0	3.0	2.6	2.6
Burrowing Animal Protection	2.5	2.8	2.6	2.7	1.0	1.0
Settlement Deterioration Protect.	2.0	2.2	1.8	2.0	2.5	2.5
Sun/UV Resistant Yes-2 No-1	2.0	2.0	2.0	2.0	2.0	2.0
Cover Erosion Functionality	2.5	2.5	2.5	2.5	2.0	2.0
Puncture Vulnerability Def.	2.0	2.5	2.0	2.2	0.1	0.1
# of Layers Required	1	1	1	1	1 or 2	1 or 2
Fits What Alternative?	#2	#2	#2	#2	#1 or #2	#1 or #2
Tech Advantages Yes=2	2.0	2.5	2.0	2.6	3.1	2.8
Tech Disadvantages Y=0 N=1	0.7	0.8	0.7	0.9	0	0
Use for Side Drainage**	2.0	2.0	2.0	2.0	2.0	2.0
Can Support Side Slope**	2.8	3.0	2.4	2.6	-	-
Materials Cost (\$per sq. ft)	.30	.32-37	.47	.30-.50	\$32/ton	\$32/ton
Shipping Cost (\$per sq. ft)	.06 or	.06 or	.00	.06-.08	\$31.91/ton+	\$31.91/ton+
Shipping Cost per truckload	\$2,000	\$2,000	.00	Subject	\$15truck/rail	\$15truck/rail
Maintenance Cost/Installed	- HC	- HC	- +.10	- HC	- HC	- HC
Company Contracts**	3.0	3.0	2.9	2.9	3+	3+
Width of Rolls (feet)	13.5	13.5	15.2	15.3	-	-
Warranty Years	25	25	0	25	-	-
Length of Rolls (feet)	100	82/100	100	125	-	-
Total Rating	36.8	38.8	34.6	37.5	23.4+	23.1+
Additional Information:	Self-seals at Seams	Needle Punched Stable add Bent/ Self-seals	Add Bentonite at seams	Add Bentonite at seams Friction Interface	Did Lagoon project at Hanford, not by itself	Did Lagoon project at Hanford, not by itself

**Good=3 Fair=2 Poor=1
HC=Hanford Company

TABLE A3 - DECISION MATRIX: GEOSYNTHETIC CLAY LINERS(GCLs) AND BENTONITE

PROPERTY	TEST METHOD	UNITS	ROLL VALUE	910SC	200ST
MECHANICAL			SLT FENCE (SOIL STABILIZATION) (ST)		
Grab Tensile Strength MD/XD	ASTM D-4632	lbs	TYPICAL	125/125	240/240
			MARV	100/100	200/200
Grab Elongation MD/XD	ASTM D-4632	%	TYPICAL	21/21	25/25
			MARV	15/15	15/15
Puncture Strength	ASTM D-4833	lbs	TYPICAL	70	120
			MARV	58	100
Mullen Burst	ASTM D-3786	psi	TYPICAL	300	500
			MARV	265	450
Trapezoidal Tear MD/XD	ASTM D-4533	lbs	TYPICAL	65/65	110/125
			MARV	50/50	85/90
HYDRAULIC					
Apparent Opening Size (AOS)	ASTM D-4751	US Sieve/mm	TYPICAL	20-30/ .850-.600	30-40/ .600-.425
			MARV	20/ .850	30/ .600
Permittivity, ψ	ASTM D-4491	sec ⁻¹	TYPICAL	0.23	.13
			MARV	0.20	.07
Water Flow Rate	ASTM D-4491	gpm/ft ²	TYPICAL	26	17
			MARV	N/A	6
ENDURANCE					
UV Resistance	ASTM D-4355 Xenon Arc	% Retained @ 500 hrs	TYPICAL	90	90
			MARV	90	90
STANDARD PACKAGING					
Roll Width	Measured	in	TYPICAL	24/36/42	150/180/210
Roll Length	Measured	ft	TYPICAL	Varies	432/360/309
Roll Area	Calculated	sq yds	TYPICAL	Varies	600
Gross Roll Weight	Measured	lbs	TYPICAL	Varies	220

NOTES

▲ "MARV" indicates minimum average roll values; calculated as the mean minus two standard deviations, yielding a 95 percent confidence level.

▲ "MD" indicates machine / warp / roll direction.

"XD" indicates cross-machine / fill / across the roll direction.

▲ Wide width tensile strength values available (ASTM D4595) from manufacturer for soil reinforcement applications.

▲ Product has typical or average value of 75% filtration efficiency and 0.35 gpm/ft², when tested in accordance with VTM-51 test method.

910SC**200ST****TABLE A4 - PRODUCT: WOVEN SLIT FILM, "TYPE 200ST"**

WHC-SD-ES-357, Rev.0

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(Release of Gundle copyrighted material was not received)

FRICTION SEAL™ HD GEOMEMBRANE

QUALITY CONTROL SPECIFICATIONS

60 mil

FRICTION SEAL HD, National Seal Company's advanced textured high density polyethylene (HDPE) geomembrane, is manufactured by attaching a friction surface to NSC's high quality HDPE geomembrane. The friction surface is made from high molecular weight polyethylene resin compounded specifically for use in NSC geomembranes. The resin has been formulated to provide stress crack, chemical and ultraviolet resistance for fluid containment. NSC produces FRICTION SEAL HD with a textured surface on one or both sides of the parent sheet.

The following properties are tested as a part of NSC's quality control program. Certified test results for properties on this page are available upon request. Refer to NSC's Quality Control Manual for exact test methods and frequencies.

RESIN PROPERTIES	METHOD	UNITS	MINIMUM ¹	TYPICAL
Melt Flow Index ²	ASTM D 1238	g/10 min	0.50	0.25
Oxidative Induction Time	ASTM D 3895, Al pan, 200°C, 1 atm O ₂	minutes	100	120
SHEET PROPERTIES	METHOD	UNITS	MINIMUM ¹	TYPICAL
Mass per Unit Area ³	ASTM D 3776	lb/ft ²	0.31	0.32
Thickness ⁴	ASTM D 751, NSF mod.			
Average		mils	60.0	61.5
Individual		mils	57.0	59.7
Density ⁴	ASTM D 1505	g/cm ³	0.940	0.948
Carbon Black Content ⁴	ASTM D 1603	percent	2.0-3.0	2.35
Carbon Black Dispersion ⁴	ASTM D 3015, NSF mod.	rating	A1, A2, B1	A1
Tensile Properties ⁵	ASTM D 638			
Stress at Yield		psi	2200	2750
		ppl	132	169
Stress at Break		psi	2200	3240
		ppl	132	199
Strain at Yield	1.3" gage length (NSF)	percent	13.0	17.5
Strain at Break	2.0" gage or extensometer	percent	200	540
	2.5" gage length (NSF)	percent	160	432
Dimensional Stability ^{2,4}	ASTM D 1204, NSF mod.	percent	1.5	0.4
Tear Resistance	ASTM D 1004	ppl	750	1000
		lbs	45	62 ←
Puncture Resistance	ASTM D 4833	ppl	1800	2276
		lbs	108	140 ←
Constant Load ESCR, Single Point ⁴	GRI, GM-5a	hours	200	>400
Friction Angle, Index	GRI, GS-7	degrees	40	56 ←

¹ This value represents the minimum acceptable test value for a roll as tested according to NSC's Manufacturing Quality Control Manual. Individual test specimen values are not addressed in this specification except thickness.

² Indicates Maximum Value

³ Friction Coating on both sides of base sheet

⁴ Testing performed on base sheet

⁵ Stress and strength values are normalized to the nominal base sheet thickness. NSC certifies properties based on values calculated using nominal thickness only. Stress values calculated using actual product thickness is not guaranteed due to the lack of industry accepted thickness test procedures for friction sheet.

FRICTION SEAL™ HD GEOMEMBRANE **PHYSICAL PROPERTIES**

60 mil

The properties on this page are not part of NSC's Manufacturing Quality Control program and are not included on the material certifications. Seam testing is the responsibility of the installer and/or CQC personnel.

PROPERTIES	METHOD	UNITS	MINIMUM ¹	TYPICAL
Multi-Axial Tensile Elongation	GRI, GM-4	percent	20.0	22.3
Critical Cone Height	GRI, GM-3, NSC mod.	cm	1.0	1.5
Wide Width Tensile	ASTM D 4885			
Stress at Yield		psi	2000	2110
Strain at Yield		%	15.0	20.0
Brittleness Temp. by Impact ²	ASTM D 746	°C	-75	<-90
Coef. of Linear Thermal Exp. ²	ASTM D 696	°C ⁻¹	1.5×10^{-4}	1.2×10^{-4}
ESCR, Bent Strip	ASTM D 1693	hours	1500	>10,000
Hydrostatic Resistance	ASTM D 751	psi	450	550
Modulus of Elasticity	ASTM D 638	psi	80,000	116,000
Ozone Resistance ⁴	ASTM D 1149, 168 hrs	P/F	P	P
Permeability ^{2,4}	ASTM E 96	cm/sec · Pa	2.3×10^{-14}	8.1×10^{-15}
Puncture Resistance	FTMS 101, method 2065	ppi	1300	1570
		lbs	78	97
Soil Burial Resistance ²	ASTM D 3083, NSF mod.	% change	10	0
Tensile Impact	ASTM D 1822	ft lbs/in ²	130	160
Volatile Loss ²	ASTM D 1203, A	percent	0.10	0.08
Water Absorption ^{2,4}	ASTM D 570, 23°C	percent	0.10	0.04
Water Vapor Transmission ^{2,4}	ASTM E 96	g/day · m ²	0.024	0.009

SEAM PROPERTIES	METHOD	UNITS	MINIMUM ¹	TYPICAL
Shear Strength	ASTM D 4437, NSF mod.	psi	2000	2700
		ppi	120	166
Peel Strength	ASTM D 4437, NSF mod.	psi	1500	1870
(hot wedge fusion)		ppi	90	115
Peel Strength	ASTM D 4437, NSF mod.	psi	1300	1590
(fillet extrusion)		ppi	78	98

STANDARD ROLL DIMENSIONS

Length	850 feet	Area	12,750 ft ²
Width	15 feet	Weight	3,950 lbs

This information contained herein has been compiled by National Seal Company and is, to the best of our knowledge, true and accurate. All suggestions and recommendations are offered without guarantee. Final determination of suitability for use based on any information provided, is the sole responsibility of the user. There is no implied or expressed warranty of merchantability or fitness of the product for the contemplated use.

NSC reserves the right to update the information contained herein in accordance with technological advances in the material properties.

6FH-0893

WHC-SD-ES-357, Rev.0

FRICTION SEAL® HD GEOMEMBRANE SPECIFICATIONS

(Update provided by
National Seal Co. for
current information
contact National Seal Co.)

60 mil (1.5 mm)

FRICTION SEAL HD, National Seal Company's textured high density polyethylene (HDPE) geomembrane, is manufactured by attaching a friction surface to NSC's high quality DURA SEAL® HD. FRICTION SEAL HD is made from high molecular weight polyethylene resin compounded specifically for use in NSC geomembranes. The resin has been formulated to be resistant to chemicals, ultraviolet degradation, as well as leaching additives. NSC produces FRICTION SEAL HD with a textured surface on one or both sides of the base sheet.

Refer to NSC's Manufacturing Quality Control Manual to determine the test methods and frequencies used as a part of NSC's quality control program.

RESIN PROPERTIES	METHOD	UNITS	MINIMUM ¹	TYPICAL
Melt Flow Index ²	ASTM D 1238	g/10 min	0.50	0.25
Oxidative Induction Time	ASTM D 3895, Al pan, 200°C, 1 atm O ₂	minutes	100	120

SHEET PROPERTIES	METHOD	UNITS	MINIMUM ¹	TYPICAL
Mass per Unit Area	ASTM D 5261	lb/ft ²	0.31	0.32
Thickness ³	ASTM D 5199			
Average		mils	60.0	61.5
Individual		mils	57.0	59.7
Density ³	ASTM D 1505	g/cm ³	0.940	0.948
Carbon Black Content ³	ASTM D 4218	percent	2.0	2.49
Carbon Black Dispersion ³	ASTM D 5596	rating	A1, A2, B1	A1
Tensile Properties ⁴	ASTM D 638			
Stress at Yield		psi	2200	2661
		ppi	132	164
Stress at Break		psi	2300	3945
		ppi	138	242
Strain at Yield	1.3" gage length (NSF)	percent	13.0	16.2
Strain at Break	2.0" gage or extensometer	percent	200	678
	2.5" gage length (NSF)	percent	160	542
Dimensional Stability ^{2,3}	ASTM D 1204, NSF mod.	percent	1.5	0.4
Tear Resistance	ASTM D 1004	ppi	750	947
		lbs	45	58
Puncture Resistance	ASTM D 4833	ppi	1800	2358
		lbs	108	145
Constant Load ESCR, ³	ASTM D 5397	hours	200	>400

¹ This value represents the minimum acceptable test value for a roll as tested according to NSC's Manufacturing Quality Control Manual. Individual test specimen values are not addressed in this specification except thickness.

² Indicates Maximum Average Roll Value.

³ Testing performed on base sheet.

⁴ Stress values are normalized to the nominal base sheet thickness. NSC certifies properties based on values calculated using nominal base sheet thickness only. Stress values calculated using actual product thickness is not guaranteed due to the lack of industry accepted thickness test procedures for friction sheet.

WHC-SD-ES-357, Rev.0

FRICTION SEAL® HD GEOMEMBRANE PHYSICAL PROPERTIES

60 mil (1.5 mm)

The properties on this page are not part of NSC's Manufacturing Quality Control program and are not included on the material certifications. Seam testing is the responsibility of the installer and/or CQC personnel.

PROPERTIES	METHOD	UNITS	MINIMUM ¹	TYPICAL
Multi-Axial Tensile Elongation	ASTM D 5617	percent	20.0	22.3
Critical Cone Height	ASTM D 5514	cm	1.0	1.5
Wide Width Tensile ³	ASTM D 4885			
Stress at Yield		psi	2000	2110
Strain at Yield		%	15.0	20.0
Brittleness Temp. by Impact ²	ASTM D 746	°C	-75	<-90
Coef. of Linear Thermal Exp. ²	ASTM E 831	°C ⁻¹	1.5×10^{-4}	1.2×10^{-4}
ESCR, Bent Strip	ASTM D 1693	hours	1500	>10,000
Hydrostatic Resistance	ASTM D 751	psi	450	550
Modulus of Elasticity	ASTM D 638	psi	80,000	116,000
Ozone Resistance ³	ASTM D 1149, 168 hrs	P/F	P	P
Permeability ^{2,3}	ASTM E 96	cm/sec · Pa	2.3×10^{-14}	6.1×10^{-15}
Puncture Resistance	FTMS 101, method 2065	ppi	1300	1545
		lbs	78	95
Soil Burial Resistance ^{2,3}	ASTM D 3083, NSF mod.	% change	10	0
Tensile Impact	ASTM D 1822	ft lbs/in ²	130	160
Volatile Loss ²	ASTM D 3030	percent	0.10	0.08
Water Absorption ^{2,3}	ASTM D 570, 23°C	percent	0.10	0.04
Water Vapor Transmission ^{2,3}	ASTM E 96	g/day · m ²	0.024	0.009

SEAM PROPERTIES	METHOD	UNITS	MINIMUM ¹	TYPICAL
Shear Strength *	ASTM D 4437, NSF mod.	psi	2000	2700
		ppi	120	166
Peel Strength	ASTM D 4437, NSF mod.	psi	1500	1870
(hot wedge fusion)		ppi	90	115
Peel Strength	ASTM D 4437, NSF mod.	psi	1300	1590
(fillet extrusion)		ppi	78	98

STANDARD ROLL WIDTH

15 FT.

This information contained herein has been compiled by National Seal Company and is, to the best of our knowledge, true and accurate. All suggestions and recommendations are offered without guarantee. Final determination of suitability for use based on any information provided, is the sole responsibility of the user. There is no implied or expressed warranty of merchantability or fitness of the product for the contemplated use.

NSC reserves the right to update the information contained herein in accordance with technological advances in the material properties.

6FH-0895

Product Name

**BLACK HILLS
GEL**

TECHNICAL DATA SHEET

DESCRIPTION

*Polymer Extended Wyoming Sodium Bentonite

APPLICATION

Recommended for oil well drilling, slurry trenching, pond sealing, and most other civil engineering applications.

TYPICAL YIELD

Black Hills Gel will yield 91 barrels (minimum) of API fluid to one ton of material.

TYPICAL CHEMICAL ANALYSIS

ELEMENT	%	ELEMENT	%
SiO ₂	64.7	CaO	1.3
Al ₂ O ₃	17.6	K ₂ O	.46
Fe ₂ O ₃	4.4	Na ₂ O	2.5
MgO	1.8	TiO ₂	.16
		H ₂ O (Crystal)	5.9

SPECIFICATIONS

SPECIFICATIONS	TYPICAL ANALYSIS	API SPECIFICATIONS
Fann @ 600 rpm	35-40	30.0
Fann @ 300 rpm	25-30	
Plastic Viscosity	10	
Yield Point Lbs./100 sq. ft.	15.0	3 X P.V. Maximum
Filtrate	13.5 ml.	15.0 Maximum
Dry Sieve Analysis	75-80% (-200 mesh)	
Wet Sieve Analysis	2.5 - 3.0%	4.0% Maximum
Moisture	7.0 - 9.0%	10.0% Maximum
pH (6.0% solution)	8.5 - 9.5	

Testing conforms to API specification 13A.

The information contained herein is based on tests believed to be reliable, however no warranty is implied.

*NOTE: This product has been treated with a small amount (.025%) of non toxic polyacrylate polymer to strengthen the viscosity of the bentonite. Please write or call if further information is needed on this.

Black Hills Bentonite Co.

A Limited Liability Co.

P.O. Box 9
Mills, WY 82644

Ph. (307) 265-3740
FAX (307) 235-8511

C L A Y M A X®**GEOSYNTHETIC CLAY LINER****CLAYMAX® 500SP SHEAR-PRO****MATERIAL SPECIFICATIONS**

Primary Backing (Typical Properties) — Polypropylene is nonbiodegradable and inert to most chemicals, acids and alkalis.

Color	Natural white
Filler Fiber	Nylon
Substrate	24 x 10 Delustered woven polypropylene, non-toxic, water permeable
Weight	4 oz. per square yard
Tensile Strength	78 lbs. per inch (minimum)
Grab Strength (ASTM D-1482)	Warp 95 lbs., Fill 70 lbs.
Mullen Burst Strength (ASTM D774)	250.25 lbs. per square inch
Puncture Strength (1/2" mandril ASTM D3787 MOD.)	249 lbs.
Melting Point	329° F
Elongation (ASTM D-1482)	Warp 15%, Fill 18%
Shrinkage—Hot Water	Nil
Shrinkage—Dry (20 min. @ 270°F)	2%

Cover Fabric	100% spunlace polyester; open weave allows for expansion of bentonite
Weight	1 oz. per square yard
Grab Strength	Warp 30 lbs., Fill 13.6 lbs.
Burst Strength	35 lbs. per square inch

Bentonite Sizing (Sodium Montmorillonite)	Specialty graded, 6 mesh and 30 mesh granules
Mineralogical Composition	90% Montmorillonite (min.)

Adhesive	Water soluble, non-toxic
Storage	On dry ground, under roof or other protective covering

The manufacturer reserves the right to change product specifications and instructions/limitations without notice. Information contained herein supersedes previously printed material prior to 7/89.

CLAYMAX® PRODUCT SPECIFICATION

Sodium Bentonite Content	1.0 lbs. per square foot
Thickness	1/4 inch
Liner Dimensions	13.5 feet x 82 feet
Effective Area Covered	1059.5 square feet (assume 6" overlap along one side and one end)
Roll Weight/Unit	1130 lbs. (minimum)
Permeability Coefficient	2×10^{-10} cm per second @ 35' head pressure.

LABORATORY TEST DATA

Procedure — Six inches of silica sand covering CLAYMAX liner in a triaxial cell under thirty-five feet of water head pressure.

GROUP	PERMEANT	PERMEABILITY
Water	De-Aired Water	2×10^{-10} cm/sec.
Salt	Seawater	2×10^{-10} cm/sec.
Acid	Acetic Acid Phosphoric Acid	2×10^{-10} cm/sec. 2×10^{-9} cm/sec.
Calcium	Calcium Chloride	2×10^{-9} cm/sec.
Alcohol	Ethyl Alcohol	2×10^{-9} cm/sec.
Organics	Methylene Chloride	3×10^{-10} cm/sec.
Leachate	Sewage BOD-38,000 Paper Pulp Sludge	8×10^{-10} cm/sec. 2×10^{-10} cm/sec.
Hydrocarbons	Jet Fuel Diesel Fuel Unleaded Gasoline	8×10^{-10} cm/sec. 8×10^{-10} cm/sec. 2×10^{-10} cm/sec.
Pressure	150 foot Water Head	1×10^{-9} cm/sec.

Additional tests are available upon request.

The above test performance data were produced under laboratory conditions. The actual performance characteristics may vary. No performance warranty is express or implied.

PACKAGING AND SHIPPING

Roll Content	1107.0 square feet
Roll Weight	1135 lbs. (approx.) wrapped
Roll Size	14.5 feet long (PVC wrapped) x 18" diameter (approx.)

James Clem Corporation

444 North Michigan, Suite 1610, Chicago, IL 60611 USA
Phone: 312.321-6255 Fax: 312.321-6258

CLAYMAX®**GEOSYNTHETIC CLAY LINER MATERIAL SPECIFICATIONS**
(ENGLISH)

	PROPERTY	TEST METHOD (1)	UNITS	CLAYMAX STYLE 2008 30 (MARV)	CLAYMAX STYLE 500SP 30 (MARV)
	FREE SWELL	USP-NF-XVII	ml		
PROPERTIES OF BENTONITE REMOVED FROM FINISHED PRODUCT	FLUID LOSS	API 13 A	ml	15 (MAX. A.R.V.)	15 (MAX. A.R.V.)
	PLATE WATER ABSORPTION	ASTM E946	%	800 (MARV)	800 (MARV)
	MOISTURE CONTENT (3)	ASTM D4643	%	20 (TYP)	20 (TYP)
	ADHESION	VISUAL	—	CONTINUOUS ADHESION TO BACKING MATERIAL	CONTINUOUS ADHESION TO BACKING MATERIAL
ADHESIVE	THICKNESS	ASTM D1777	inches	0.2 (TYP)	0.2 (TYP)
PHYSICAL PROPERTIES	WIDE WIDTH TENSILE	ASTM D4595	lb/in	60 (TYP) (2)	100 (TYP)
	GRAB TENSILE	ASTM D4632	lb	90 (MARV) (2)	90 (MARV) (2)
	BENTONITE CONTENT (3) @ 20% moisture	WEIGH 12" x ROLL WIDTH	lb/sf	0.95 (MARV)	0.95 (MARV)
	SHEAR RESISTENCE				
	HYDRATED	ASTM D35.01.81.07	—	10 DEGREES (TYP)	500 psf (TYP) (4)
	DRY	(DRAFT)	—	35 DEGREES (TYP)	500 psf (TYP) (4)
	PERMEABILITY				
HYDRAULIC PROPERTIES	A) 5 psi EFFECTIVE STRESS	ASTM D5084	cm/s	5 E - 9 (MAX)	5 E - 9 (MAX)
	B) 5 psi EFFECTIVE STRESS OVERLAPPED CLAYMAX (5) (WITHOUT THE USE OF GRANULAR BENTONITE BETWEEN THE SEAMS)	ASTM D5084	cm/s	5 E - 9 (MAX)	5 E - 9 (MAX)
	C) 30 psi EFFECTIVE STRESS	ASTM D5084	cm/s	<5 E - 10 (TYP)	<5 E - 10 (TYP)
	D) 5 psi EFFECTIVE STRESS DAMAGED CLAYMAX (3 EACH, 1" HOLES)	ASTM D5084	cm/s	<5 E - 9 (TYP)	<5 E - 9 (TYP)
	E) 5 psi EFFECTIVE STRESS AFTER 3 WET/DRY CYCLES	ASTM D5084	cm/s	<5 E - 9 (TYP)	<5 E - 9 (TYP)
	F) 5 psi EFFECTIVE STRESS AFTER 3 FRZ/THAW CYCLES	ASTM D5084	cm/s	<5 E - 9 (TYP)	<5 E - 9 (TYP)

(1) Standard test methods modified where appropriate to facilitate testing on Geosynthetic Clay Liner (GCL).

(2) Machine (warp) direction of primary backing.

(3) D4643 modified to include wet weight as the denominator.

(4) Internal shear strength of CLAYMAX® 500SP is independent of confining stress.

(5) 6" overlap in 12" permeameter cell.

**TABLE A8 - PRODUCT: "CLAYMAX 500SP", GEOSYNTHETIC CLAY LINER(GCL) -
(Cont.)**

#S9200

CLAYMAX®

GEOSYNTHETIC CLAY LINER MATERIAL SPECIFICATIONS

(SI)

	PROPERTY	TEST METHOD (1)	UNITS	CLAYMAX STYLE 200R	CLAYMAX STYLE 500SP
PROPERTIES OF BENTONITE — REMOVED FROM FINISHED PRODUCT	FREE SWELL	USP-NF-XVII	ml	30 (MARV)	30 (MARV)
	FLUID LOSS	API 13 A	ml	15 (MAX. A.R.V.)	15 (MAX. A.R.V.)
	PLATE WATER ABSORPTION	ASTM E946	%	800 (MARV)	800 (MARV)
	MOISTURE CONTENT (3)	ASTM D4643	%	20 (TYP)	20 (TYP)
ADHESIVE	ADHESION	VISUAL	—	CONTINUOUS ADHESION TO BACKING MATERIAL	CONTINUOUS ADHESION TO BACKING MATERIAL
PHYSICAL PROPERTIES	THICKNESS	ASTM D1777	mm	5 (TYP)	5 (TYP)
	WIDE WIDTH TENSILE	ASTM D4595	KN/m	10.5 (TYP) (2)	17.5 (TYP)
	GRAB TENSILE	ASTM D4632	KN	0.4 (MARV) (2)	0.4 (MARV) (2)
	BENTONITE CONTENT (3) @ 20% moisture	WEIGH 0.3m x ROLL WIDTH	kg/m ²	4.6 (MARV)	4.6 (MARV)
	SHEAR RESISTANCE				
	HYDRATED	ASTM D35.01.81.07	—	10 DEGREES (TYP)	24 KPa (TYP) (4)
	DRY	(DRAFT)	—	35 DEGREES (TYP)	24 KPa (TYP) (4)
HYDRAULIC PROPERTIES	PERMEABILITY				
	A) 35 KPa EFFECTIVE STRESS	ASTM D5084	m/s	5 E - 11 (MAX)	5 E - 11 (MAX)
	B) 35 KPa EFFECTIVE STRESS OVERLAPPED CLAYMAX (5) (WITHOUT THE USE OF GRANULAR BENTONITE BETWEEN THE SEAMS)	ASTM D5084	m/s	5 E - 11 (MAX)	5 E - 11 (MAX)
	C) 200 KPa EFFECTIVE STRESS	ASTM D5084	m/s	<5 E - 12 (TYP)	<5 E - 12 (TYP)
	D) 35 KPa EFFECTIVE STRESS DAMAGED CLAYMAX (3 EACH, 25MM HOLES)	ASTM D5084	m/s	<5 E - 11 (TYP)	<5 E - 11 (TYP)
	E) 35 KPa EFFECTIVE STRESS AFTER 3 WET/DRY CYCLES	ASTM D5084	m/s	<5 E - 11 (TYP)	<5 E - 11 (TYP)
	F) 35 KPa EFFECTIVE STRESS AFTER 3 FRZ/THAW CYCLES	ASTM D5084	m/s	<5 E - 11 (TYP)	<5 E - 11 (TYP)

(1) Standard test methods modified where appropriate to facilitate testing on Geosynthetic Clay Liner (GCL).

(2) Machine (warp) direction of primary backing.

(3) D4643 modified to include wet weight as the denominator.

(4) Internal shear strength of CLAYMAX® 500SP is independent of confining stress.

(5) 150 mm overlap in 300 ml permeameter cell.

TABLE A8 - PRODUCT: "CLAYMAX 500SP", GEOSYNTHETIC CLAY LINER(GCL) -
(Cont.)

LABORATORY TEST DATA ON CLAYMAX®

PERMEABILITY TESTS ON CLAYMAX

Procedure: Six inches of silica sand covering CLAYMAX liner in a triaxial cell under thirty-five feet of water pressure.

TEST WITH CLAYMAX HYDRATED BY PERMEANT

Group	Permeant	Permeability	Tested By*	Date
Water	De-Aired Water	2×10^{-10} cm/s	STS	9/25/83
Salt	Seawater	2×10^{-10} cm/s	GS	11/29/88
Leachates	Sewage BOD > 38,000	8×10^{-10} cm/s	STS	5/11/89
	Paper Pulp Sludge	2×10^{-10} cm/s	STS	6/03/88
	Pond Sludge	2×10^{-9} cm/s	STS	1/03/85
	Ash	1×10^{-10} cm/s	STS	4/24/89
Pressure	150 ft Water	1×10^{-9} cm/s	STS	11/19/86

TEST WITH CLAYMAX PREHYDRATED BY DE-AIRED WATER

Group	Permeant	Permeability	Tested By*	Date
Acid	1% Acetic Acid (pH 1)	2×10^{-10} cm/s	STS	11/28/83
	Phosphoric Acid	1×10^{-9} cm/s after 8 days	STS	11/16/87
Alkali	20% Hydrated Lime (pH 14)	6×10^{-10} cm/s	STS	10/05/81
Calcium	Calcium Chloride	2×10^{-9} cm/s	STS	4/27/83
	Calcium Lignosulfonate	2×10^{-9} cm/s after 21 days	STS	10/16/87
Alcohol	Ethyl Alcohol 10%	2×10^{-8} cm/s	STS	9/25/83
Organics	Methylene Chloride	4×10^{-10} cm/s	STS	2/12/88
Hydrocarbons	No. 1 Diesel Fuel	9×10^{-10} cm/s	STS	7/07/89
	Jet Fuel	9×10^{-10} cm/s	STS	7/07/89
	Unleaded Gasoline	2×10^{-10} cm/s	STS	7/07/89
	Gasahol	2×10^{-10} cm/s	STS	7/07/89
	MTBE	7×10^{-10} cm/s	STS	7/17/90

MECHANICAL PROPERTIES TESTING

Property	Test Details	Results	Tested By*	Date
Puncture Strength (ASTM D 3787)	Punctured with 8mm diameter solid steel rod at a strain rate of 12 in/min	39 kg, 86 lbs	STS	5/26/87
Shear Strength			GS	3/10/89
	<u>Slip Plane Interface</u>	<u>Friction Angle (ϕ), Cohesion (C)</u>		
	Between geotextile of CLAYMAX and dry PVC membrane	$\phi = 15.0^\circ$ $C = .239$ KSC		
	Within bentonite layer of hydrated CLAYMAX	$\phi = 11.5^\circ$ $C = .500$ KSC		
	Between silty sand and geotextile of CLAYMAX	$\phi = 17^\circ$ $C = .273$ KSC		
	Between geotextile of CLAYMAX and dry, smooth HDPE	$\phi = 17^\circ$ $C = .300$ KSC		
Wide Width Tensile Strength			GS	4/19/88
	Creep Strength	420 lbs/ft		
	Maximum Tensile Load	1440 lbs/ft		

* GS = GeoServices Inc., Atlanta, GA; STS = STS Consultants Ltd., Deerfield, IL; TL = Tex Lab, Inc.

TABLE A8 - PRODUCT: "CLAYMAX 500SP", GEOSYNTHETIC CLAY LINER(GCL) -
(Cont.)

LABORATORY TEST DATA ON CLAYMAX® (cont.)

PHYSICAL PROPERTIES TESTING

PERMEABILITY EFFECTS FOR VARIOUS CONDITIONS

Type of Test	Test Details	Permeability	Tested By*	Date
Freeze-Thaw Effects	Samples were hydrated following exposure to 0, 1, 5, 10 and 20 freeze-thaw cycles.	2×10^{-10} cm/s	GS	12/88
Puncture Effects	Punctured with 1/2" diameter rod: prior to saturation after saturation	2×10^{-6} cm/s (initial) 4×10^{-9} cm/s (after 9 days) 9×10^{-7} cm/s (initial) 8×10^{-10} cm/s (after 5 days)	STS	3/20/86
Seam Overlap	2" overlap @ center of 4' diameter sample	7×10^{-10} cm/s	STS	7/16/84
Strain Effects	CLAYMAX stretched 15% of original length	4×10^{-10} cm/s	STS	4/18/88

PHYSICAL CHARACTERISTICS FOR VARIOUS CONDITIONS

Property	Test Details	Results	Tested By*	Date
Swell Potential	Percent of swell of original height of CLAYMAX	9% @ 1,500 KSC load 132% @ .004 KSC load	STS	7/15/87
Unsupported Slope Length			GS	4/19/88
Assuming soil/fabric friction angle of 15°; 6-9 in. cover material at a density of 130 P.C.F.; factor of safety = 1.5; 40 lbs/in creep strength.	<u>Slope</u> 4:1 3:1 2.5:1 2:1	<u>Maximum Length</u> 45 ft 27 ft 20 ft 15 ft		
Transmissivity of Net Under CLAYMAX	(Results for a gradient of 1.0) @ 1000 PSF confining stress @ 20,000 PSF confining stress	4.7 gpm 2.1 gpm	GS	4/19/88
Moisture Retention			GS	7/14/89
		<u>Time (days)</u> 0 (saturated) 4 21 47 90	<u>Moisture Content</u> 1300% 690% 15% 6% 1%	
CLAYMAX placed in a temperature and humidity controlled chamber to simulate exposure to long term arid environments. Different overburden pressures were applied to each of the three samples to simulate various soil cover conditions.	Using zero confining stress			
	8 inches of overburden soil placed on CLAYMAX	0 (saturated) 25 90 154 235 294	260% 280% 260% 180% 20% 1%	
	18 inches of overburden soil placed on CLAYMAX	0 (saturated) 25 90 154 235 294	300% 265% 248% 203% 116% 37%	

The preceding test performance data does not represent product specifications. The tests were performed under laboratory conditions by certified independent testing labs. The actual performance characteristics may vary. No performance warranty expressed or implied.

* GS = GeoServices Inc., Atlanta, GA; STS = STS Consultants Ltd., Deerfield, IL; TL = Tex Lab, Inc.

TABLE A8 - PRODUCT: "CLAYMAX 500SP", GEOSYNTHETIC CLAY LINER(GCL) -
(Cont.)

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY

(This update was provided
by CETCO, contact CETCO
for current data)

234 Gordon Street • Fairmount, GA 30139 • USA
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CLAYMAX 200R CERTIFIED PROPERTIES

MATERIAL	QUALITY PARAMETER	TEST METHOD ¹	TEST FREQUENCY	CERTIFIED VALUE
Woven Geotextile	Grab Strength	ASTM D 4632	Supplier Certified	90 lbs
	Grab Elongation	ASTM D 4632	Supplier Certified	15%
	Mass/Area	ASTM D 5261	Supplier Certified	3.25 oz/ft ²
Bentonite	Free Swell	USP-NF-XVII	1 per 50 tons	24 ml
	Fluid Loss	API 13A/13B	1 per 50 tons	15 ml
Claymax 200R	Bentonite Mass Per Unit Area ²	Direct Measurement 1' x roll width	15,000 ft ²	0.95 lbs/ft ²
	Grab Strength ³	ASTM D 4632	Periodic	180 lb
	Wide Width Tensile ³	ASTM D 4632	Periodic	50 lb per inch (ppi)
	Permeability	ASTM D 5084	1 per Production Week	5 x 10 ⁻⁹ cm/sec

NOTES:

- 1) Standard test methods modified where appropriate to facilitate testing of a geosynthetic clay liner (GCL).
- 2) ASTM D 4643 modified to include wet weight in the denominator.
- 3) Wide width and grab tensile tests in machine direction only.

CLAYMAX 500SP CERTIFIED PROPERTIES

MATERIAL	QUALITY PARAMETER	TEST METHOD ¹	TEST FREQUENCY	CERTIFIED VALUE
Woven Geotextile	Grab Strength	ASTM D 4632	Supplier Certified	90 lbs
	Grab Elongation	ASTM D 4632	Supplier Certified	15%
	Mass/Area	ASTM D 5261	Supplier Certified	3.25 oz/ft ²
Bentonite	Free Swell	USP-NF-XVII	1 per 50 tons	24 ml
	Fluid Loss	API 13A/13B	1 per 50 tons	15 ml
Claymax 500SP	Bentonite Mass Per Unit Area ²	Direct Measurement 1' x roll width	15,000 ft ²	0.95 lbs/ft ²
	Grab Strength ³	ASTM D 4632	Periodic	180 lb
	Wide Width Tensile ³	ASTM D 4632	Periodic	80 lb per inch (ppi)
	Hydrated Internal Shear Strength	ASTM D 5321	Periodic	5 degrees and 550 psf
	Permeability	ASTM D 5084	1 per Production Week	5 x 10 ⁻⁹ cm/sec

NOTES:

- 1) Standard test methods modified where appropriate to facilitate testing of a geosynthetic clay liner (GCL).
- 2) ASTM D 4643 modified to include wet weight in the denominator.
- 3) Wide width and grab tensile tests in machine direction only.

TOTAL SURFACE AREA OF FARM CORP.

METHOD: CORP. HAS A TOP AND ADJACENT SIDES. TWO

CATEGORIES ARE CALCULATED SEPARATELY THEN

THE RESULTS ARE ADDED.

CALCULATIONS

STATEMENT OF CALCULATED AREAS:

CALCULATIONS (SIDE SLOPES):

AREA #1:

AREA #2:

AREA #3:

AVER. S.L. $\approx 340'$

$$A_3 = L_w = (53.76)(53.76) = 18,278.44'$$

$$A_2 = L_w = (48.4)(25.3) = 12,245.20'$$

AVER. S.L. $\approx 484'$

$$A_1 = L_w = (332)(28.46) = 9,449.72'$$

AVER. SIDE LENGTH $\approx 332'$

TECHNICAL DATA SHEET**BENTOMAT ST CERTIFIED PROPERTIES**

MATERIAL	QUALITY PARAMETER ¹	TEST METHOD ²	TEST FREQUENCY	CERTIFIED VALUE ³
Woven Geotextile	Grab Strength	ASTM D 4632 ⁴	50,000 sq ft ⁵	109 lbs
	Grab Elongation	ASTM D 4632	50,000 sq ft	15 percent
	Mass/Area	ASTM D 5261	50,000 sq ft	3.3 oz/sq yd
Non-Woven Geotextile ⁶	Grab Strength	ASTM D 4632	50,000 sq ft	6.0 lbs
	Grab Elongation	ASTM D 4632	50,000 sq ft	150 percent
	Mass/Area	ASTM D 5261	50,000 sq ft	6.0 oz/sq yd min.
Bentonite ⁷	Free Swell	ACC 1010 ⁸	50,000 sq ft	24 mL/2g min.
	Fluid Loss	API 13A/13B	50,000 sq ft	15 mL max.
	Moisture Content ⁹	ACC 1009	50,000 sq ft	12 percent max.
	Particle Type: Granular ¹⁰	ASTM D 421	50,000 sq ft	100% min - #10 1% max - #200
Bentomat	Average Mass/Area	Roll Weight	Each Roll	1.0 lb/sq ft min
	Sample Mass/Area ¹¹	ASTM D 5261	20,000 sq ft	1.0 lb/sq ft min
	Moisture Content ¹²	ASTM D 4643	20,000 sq ft	25 percent typical
	Grab Strength	ASTM D 4632	20,000 sq ft	90 lbs
	Grab Elongation	ASTM D 4632	20,000 sq ft	15 percent typical
	Peel Strength	ASTM D 4632	20,000 sq ft	15 lbs minimum
	Permeability	ASTM D 5084	As Required	1 x 10 ⁻⁷ cm/sec ¹³

NOTES:

1. Please refer to the Bentomat MQA/MQC manual for additional details regarding this information. Also, the listed values of each parameter are subject to change as manufacturing processes are refined. Contact CETCO for confirmation of this information.
2. ASTM procedures modified as necessary to utilize three test specimens across the roll width. Results are reported as the average of these three values. Size of test specimens may also differ slightly from those indicated in ASTM methods.
3. All required values listed are minimum average roll values (MARVs) unless otherwise indicated.
4. All tensile testing on the geotextiles and on the Bentomat is performed with the test specimens oriented in the machine direction.
5. The listed test frequency is based on one series of tests per woven geotextile roll. This corresponds to an approximate frequency of one test per 50,000 square feet of Bentomat produced. Actual frequency of all tests may vary slightly due to varying roll dimensions.
6. The listed values represent the non-woven geotextile before being needlepunched into the Bentomat product. The actual tensile strength of the non-woven is much higher but cannot be accurately measured due to difficulties in separating it from the woven geotextile.
7. These parameters are for the bentonite before it is incorporated into the finished Bentomat product.
8. ACC method derived from general methodology outlined in USP-NF-XVII.
9. This method places the "wet weight" in the denominator. Moisture content for the finished product is determined using ASTM D 4643, which places the dry weight in the denominator.
10. All bentonite is granular type. The particle size distribution may vary slightly.
11. Mass per unit area of the bentonite component of the Bentomat, obtained by weighing an oven-dried sample of known area and subtracting the typical geotextile mass per unit area values. The resulting values are normalized to a reference moisture content of 12 percent.
12. Moisture content of the bentonite, exclusive of the geotextiles.
13. Permeability with deaired tap water at 10 psi confining stress and 5 psi head.

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The information and data contained herein are believed to be accurate and reliable. CETCO makes no warranty of any kind and accepts no responsibility for the results obtained through application of this information.

AREA #4:

AVER. S.L. $\approx 485'$

$$A_4 = lw = (485)(37) = \underline{18,115 \text{ sq'}}$$

$$\Sigma \text{Area}_{1-4} \approx \underline{58,887 \text{ sq'}}$$

CALCULATIONS (TOP):

$$\text{AREA \#5: } A_5 = \frac{bh}{2} = \frac{(310)(154)}{2} = \underline{24,024 \text{ sq'}}$$

$$\text{AREA \#6: } A_6 = lw + \frac{bh}{2} = (135)(154) + \frac{(188)(135)(2)}{2} = \underline{46,170 \text{ sq'}}$$

$$\text{AREA \#7: } A_7 = \frac{bh}{2} = \frac{(312)(142)}{2} = \underline{22,152 \text{ sq'}}$$

$$\text{AREA \#8: } A_8 = lw + \frac{bh}{2} = (177)(154) + \frac{(177)(188)(2)}{2} = \underline{60,534 \text{ sq'}}$$

$$\Sigma \text{Area}_{5-8} \approx \underline{152,880 \text{ sq'}}$$

$$\text{TOTAL Area}_{1-8} = 58,887 + 152,880 = \underline{211,767 \text{ sq'}}$$

- FOR SIMPLIFICATION, TOTAL AREA IS 212,000 sq'
- VENDOR INDICATE 12% TO 15% WASTE FOR CONSTRUCTION

THEREFORE:

$$w/12\% \text{ WASTE} \rightarrow 237,440 \text{ sq'}$$

$$w/15\% \text{ WASTE} \rightarrow 243,800 \text{ sq'}$$

TABLE A9 - GENERAL CALCULATIONS FOR PROJECT (Cont.)

PEAK CALCULATIONS:

METHOD: RATIONAL METHOD ($Q = CIA$) WAS USED TO CALCULATE FLOW OFF THE COVER. ALSO TO CHECK DATA RESULTING FROM THE RATIONAL METHOD, THE VELOCITY WAS CALCULATED USING THE FLOW FROM THE RATIONAL METHOD AND THE ROUNDED VALUE FOR TOTAL AREA PREVIOUSLY CALCULATED.

CALCULATIONS:

$$Q = CIA$$

WHERE: Q = PEAK FLOW, CFS

C = COEFFICIENT f (LAND COVER)

I = INTENSITY OF RAIN FALL (IN/HR)

NOTE: CALCULATIONS BASED ON 25 YR. EVENT,
24 HOUR DURATION

A = AREA (AC) < 10 AC.

NOTE: C % FOREST ~ 0.1

GRASS ~ 0.2

PAVEMENT ~ 0.1

ASSUME $C \approx 0.3$

$$A = 212,000 \text{ sq ft}$$

FROM REGIONAL WEATHER DATA, A 24 HR, 25 YR EVENT WOULD PRODUCE APPROXIMATELY 1.56 INCHES.

$$\frac{1.56 \text{ IN}}{24 \text{ HR}} = \frac{0.065 \text{ IN}}{\text{HR}}$$

$$AREA = 212,000 \text{ FT}^2 \left(\frac{144 \text{ IN}^2}{1 \text{ FT}^2} \right) = 30,528 (10^6) \text{ IN}^2$$

$$\therefore Q = (0.3)(0.085 \text{ IN/HR})(30,528,000 \text{ IN}^2)$$

$$= 515,216 \text{ IN}^3/\text{HR}$$

$$Q \approx \underline{344.5 \text{ FT}^3/\text{HR}}$$

VOLUME CALCULATION: (TRENCH DESIGN)

$$V = (344.5 \text{ FT}^3/\text{HR})(24 \text{ HR})$$

$$V = 8268 \text{ FT}^3$$

TRENCH CONFIGURATION

VOLUME OF TRENCH:

TRENCH PERIMETER $\sim 1806'$

WITH A CROSS-SECTIONAL AREA OF THE TRENCH @ 4.5 FT^2 ,
THE MAXIMUM VOLUME CAPACITY $\sim 8,127 \text{ FT}^3$

CONCLUSION:

DESIGN OF TRENCH IS NOT BASED ON A DETAILED ANALYSIS, BUT RATHER THE APPROACH WAS A CONSERVATIVE ONE IN WHICH THE TRENCH IS CONSIDERED A RETENTION ARE FOR A 24 HR PERIOD. POROSITY OF SOIL WAS NOT CONSIDERED THOUGH, IN REALITY, ITS VALUE WOULD INFLUENCE THE TRENCH SIZE. DOWNSIZING OF THE TRENCH IS PROBABLE.

FINISHED TRENCH

Determination of Hydraulic Conductivity

According to Darcy's Law, for steady state, laminar flow through a saturated porous medium the hydraulic conductivity, K , is defined as:

$$K = \frac{Q}{i A \Delta t}$$

Where: K = hydraulic conductivity (cm/s)
 Q = volume of outflow (cm³)
 i = hydraulic gradient (in/in)
 A = area of flow (cm²)
 Δt = time (s)

By measuring Q , i , A , and Δt , the hydraulic conductivity could be determined for each of the samples.

One can define distortion (Δ/L) as the difference in settlement between two points, (Δ), divided by the length over which the settlement occurs, (L). This is shown in Fig.

Figure
Distortion as a Result of Differential Settlement

TO USE THIS CHART, SELECT ANY DESIRED RAINFALL INTENSITY AND DURATION AND READ FROM THE DIAGONAL LINES THE EXPECTED FREQUENCY OF SUCH INTENSITY AND DURATION. FOR EXAMPLE, RAINFALL INTENSITY OF 1.3 INCHES PER HOUR FOR 10 MINUTES CAN BE EXPECTED TO OCCUR, ON AVERAGE, ONCE EVERY 5 YEARS (POINT A). HOWEVER, SUCH INTENSITY CAN BE EXPECTED FOR 30 MINUTES DURATION ONLY ABOUT ONCE IN 100 YEARS (POINT B). THE RETURN PERIOD FOR THIS INTENSITY FOR 60 MINUTES DURATION IS GREATER THAN 1000 YEARS (POINT C).

THERE ARE, OF COURSE, VARIATIONS IN USE OF THE CHART. SUPPOSE, FOR EXAMPLE, IT IS DESIRED TO FIND THE "100-YEAR STORM" FOR 60 MINUTES. THIS IS 0.8 INCH (POINT D).

Rainfall Intensity, Duration and Frequency Based on the Period 1947 to 1969 at Hanford

APPENDIX D

**"HISTORY AND ENVIRONMENTAL
PLANS AND AGREEMENTS**

**"GENERAL DESCRIPTION AND ENVIRONMENTAL
CHARACTERISTICS OF THE HANFORD SITE,
200 WEST AREA"**

History and Environmental Plans and Agreements

Major historic events for the Hanford Site are included as a complete Hanford History Timeline but Significant events extracted from this compilation and include: 1945, Hanford Plutonium was used in the "FAT MAN" device dropped over Nagasaki, Japan; 1964, President Johnson announced a cutback in nuclear materials production; 1971, President Nixon ordered all funding cut for materials production, closing N and K reactors; 1986, 40 years of environmental data was released to the public; and present cleanup efforts are underway by the DOE.

Currently, Hanford has been in the public eye more than at its origination and its cleanup is being driven and supported by increasing environmental concerns. Plans and agreements driving environmental cleanup and closure plans are discussed below. They include the Hanford Environmental Management Plan and, the Environmental Compliance and Tri-Party Agreement Implementation. They are described below.

Environmental protection and improvements are major Hanford initiatives. The "Hanford Environmental Management Plan" provides for a comprehensive environmental surveillance and compliance program, being independent of Hanford operations. DOE-RL(Richland Operations Office), with assistance from Pacific Northwest Lab(PNL), developed the plan to achieve full compliance with regulations applicable to the Hanford site. In accordance with the plan, PNL conducts a comprehensive suite of environmental programs, independent of the Operations and Engineering Contractor, to monitor and assess the impact of operations on the Site and regional environment. Major activities include ground water and surface environment, developing and implementing ground water monitoring compliance plans, projecting the impacts of future operations, and conducting environmental research and development. The responsible contractor is Westinghouse Hanford Company while the Hanford Environmental Surveillance programs have been conducted by PNL since 1965.

The "Environmental Compliance and Tri-Party Agreement Implementation" is a Hanford Federal Facility agreement or consent order. The Tri-Party agreement is a legally-binding agreement between the U.S. Department of Energy-Richland Operations Office, the Washington Department of Ecology(Ecology), and the U.S. Environmental Protection Agency(EPA). The officials signed the agreement on May 15, 1989 after two years of negotiations. The agreement's purpose is to facilitate Hanford Site compliance with Response, Compensation, and Liability Act(CERCLA, Superfund), and Washington State Hazardous Waste Management Act(HWMA) requirements.

An Action Plan in the Tri-Party agreement contains 161 scheduled milestones representing enforceable commitments for the most significant actions required to bring the Hanford site into compliance with environmental laws. These significant actions fall under five categories:

1) single-shell tank (SST) closure and final disposal of all tank wastes; 2) inactive waste disposal site investigation and cleanup; 3) treatment, storage and disposal (TSD) facility permitting and closure; 4) cessation of contaminated liquid effluent disposal to the soil column; and 5) operation of the Hanford Waste Vitrification Plant (HWVP). Recently, public exposure and concern has been directed to 1): single-shell tanks having possible fractures and being unsafe. The general categories 2), 4), and specifically 3) are the basis for the design of a Final Cover for Closure Plans and this proposal.

A method which may be implemented in the preparation of the hazardous waste contained within the soil may be the "Vitrification Process". The Vitrification Process uses a high voltage electricity sent throughout contaminated soil to immobilize and remove radioactive wastes from the soils. This melts the soil and turns it into glass, much like obsidian.

Additionally, the Tri-Party agreement provides for public involvement outlined in a Community Relations Plan. Public information repositories have been established in Richland, Olympia, Portland, and Seattle. Newsletters, press releases, public meetings and hearings will be held; and documents such as Remedial Investigation/Feasibility Study (RI/FS) Work Plans and Closure plans will be made available to the public. This proposal supports the above-mentioned Closure plan. Beginning in 1990, twenty-six milestones are scheduled including five RI/FS Work Plans, installation of 29 RCRA groundwater monitoring wells, three "Part B" permits, two Closure/Post Closure Plans, Four Closure Plans, two milestones for single shell tank sampling and interim stabilization, and six milestones for administrative reports, establishing schedules, research effort and design. Westinghouse Hanford Company has overall responsibility for implementing the agreement and performing the clean-up activities. Kaiser Engineers has responsibility for the (RCRA) Resource Conservation and Recovery Act well drilling and sampling.

General Description and Environmental Characteristics of the Hanford Site, 200 West Area

The DOE's Hanford Site is located in the semiarid Pasco Basin, a structural and topographical depression within the Columbia Plateau in southeastern Washington State. The Site occupies an area of about 560 square miles and is about 31 miles north to south, and 25 miles east to west. The Site is located on lands ceded to the U.S. government by the Yakima and Umatilla Indians. This land is restricted to public access, providing a buffer for the smaller areas currently used for operations, waste storage, and waste disposal. Adjoining lands to the west, north, and east of the Site are principally range and agricultural land (i.e. irrigated and dry farming). The Tri-Cities (Kennewick, Pasco, Richland) compose the nearest population center and are located southeast of the Site. There were 340,000 people who lived in a 50 mile radius of the center of the Site in the 1980 census. About 13,000 persons are employed on DOE-related projects at Hanford.

The normal elevation of the river is 381 feet above mean sea level and the elevation of the Columbia River reactors ground-floor levels range from 413 to 494 feet. The terrain of the central and eastern parts of the Site are relatively flat. The northern and western parts of the Site have moderate to steep topographical ridges composed of basalt and sediments. The 200-Area Plateau has undergone minimal erosion over time. The Site is bounded by the southwest, west, and north by large ridges that trend eastwardly and southeastwardly from the Cascade Range which die out within the Site's confines. The elevation of the alluvial plain, covering much of the site, ranges from 345 feet above mean sea level in the SE corner to 804 feet in the NW corner.

The 200 Area's topography is nearly flat with only local and low relief and ranges in elevation from 623 to 805 feet above sea level. This is shown in Figure A1, titled, "Topography of Waste Management Areas, 200-West Area". Also see Figure A2 showing the Geomorphic Features surrounding the 200 Area. Wastes have been buried in the 200 Areas from the start of chemical processing operations. Specifically, these wastes consist of "dry waste" (solid clothing, laboratory supplies, tool, etc, packed in cardboard, wood or metal containers) and industrial waste (primarily items of failed process equipment packaged in heavy metal or concrete boxes). Included in this waste is charcoal, lead, lead brick, lead shielding, oil, and slaked lime. Transuranic-bearing waste has been packaged in sealed metal containers and sealed in burial trenches since May 1, 1970. The contaminated solid and liquid waste from the entire Hanford Site are buried in both inactive and active low-level waste burial grounds (LLBG) in the 200 areas. The radioactive waste from decommissioning the 100-Area reactors would be buried in the 200-West Area if one of the removal or dismantlement alternatives is chosen for decommissioning.

FIGURE A1 - TOPOGRAPHY OF WASTE MANAGEMENT AREAS 3 AND 4, TRENCH W-0254 IS ALSO SHOWN

As of August 1988, 19 monitoring wells were installed by the ONWEGO Drilling Co., Inc. in the 200-West Area. Kaiser Engineering is responsible for new monitor well drilling.

Hydrology of the Site:

The primary surface water features of the Hanford Site are the Columbia and Yakima Rivers. Surface runoff from the site to these rivers is extremely low. The average annual flow of the Columbia River at Hanford is 960,00 gallons per minute, and the Yakima is about 220,000 gallons per minute. Normal Columbia River elevations range from 394 feet above mean sea level at Vernita where the river meets the Site, to 341 feet at the 300-Area where the river leaves the site. The dam regulated probable maximum flood would produce a flow of about 11.5 million gallons per minute in the Columbia River and would reach the elevation of the bottom of the fuel storage basins, but would not reach the floor of any reactor building. A 50% failure of Grand Coulee Dam would create a maximum flow of 64 million gallons per minute and flood parts of the 100 and 300 areas along with most downstream cities but would not reach the 200 areas.

Ground water occurs under the Site in both unconfined and confined aquifers. The unconfined (upper) aquifer is contained within the glaciofluvial sands and gravels in the Ringold Formation. The lower is the basalt or clay member of the lower Ringold Formation. These formations and ground water levels are shown as a cross-section in Figure A3. The confined aquifer consists of sedimentary zones occurring between dense basalt flows. Direct interconnection of the unconfined and the uppermost confined aquifers do occur. Natural recharge to the unconfined aquifer may occur in small amounts from precipitation and surface runoff. Artificial recharge to the unconfined aquifer in the 200 Areas results from disposal of waste cooling and process water to the ground. Depth of the water table averages 180 to 312 feet in the 200 Areas. The water table elevations for June 1987 are shown in Figure A4. This figure includes the 200 areas and relative ridge or elevated structural relief.

Groundwater flow directions in the 200-West Area are northerly. Vertical hydraulic gradients beneath the 200-West Area are downward within the uppermost aquifer. Results of aquifer testing for Hanford sediments are highly variable both laterally and vertically.

Contaminants are present beneath the 200 Area disposal areas. However, contamination likely originated from past operation of adjacent liquid disposal sites, not from the specific waste management areas that received solid waste.

Figure A3 is below:

FIGURE A3 - GENERALIZED EAST-WEST CROSS SECTION THROUGH THE HANFORD SITE IN THE VICINITY OF THE 200 AREAS LOW-LEVEL BURIAL GROUNDS(LLBG)

FIGURE A4 - WATER-TABLE ELEVATIONS FOR JUNE 1987 (SCHATZ et al 1987)

Water Quality, and Environmental Monitoring of the Site:

The State of Washington Department of Ecology classifies the Columbia River as Class A or excellent between Grand Coulee Dam and the mouth of the River. The DOE holds a National Pollutant Discharge Elimination System (NPDES) permit issued by the EPA for eight point source discharges into the Columbia River.

Radiological monitoring of the atmosphere, ground water, Columbia River water, foodstuffs, plants, animals, and soil is conducted routinely by the Pacific Northwest Laboratory(PNL). Groundwater monitoring wells are used for this purpose are shown in Figure A4, but additional wells have been installed since 1987 according to Westinghouse Hanford. Additional information about location, specific well construction and water table elevation as well as surface waters are shown in Figure A5 through A8.

Measurements made in 1987 show that radionuclides have entered ground water in the 200 areas and migrated easterly to the Columbia River. Samples collected from the Columbia River upstream and downstream from the Hanford Site indicate that tritium, iodine-129, gross alpha, and uranium concentrations were measurable at higher concentrations downstream from Hanford than upstream, but that all off-site concentrations are well within EPA drinking standards. The major sources of radionuclides entering the river are from the N reactor liquid-disposal facilities and from 200-Area ground water moving below the Hanford Site and into the river. Foodstuffs from the area, including those irrigated with Columbia River water, were sampled and the concentrations of radionuclides were shown to be similar to the low concentrations of food stuffs grown in adjacent areas. Some waterfowl, fish, and rabbits showed low levels of cesium-137 attributable to Hanford operations. Dose rates from external penetrating radiation measured in the vicinity of local residential areas were similar to those obtained in previous years, and no contribution from Hanford activities could be identified. Some levels of nitrate, chromium, fluoride, and carbon tetrachloride were found in ground-water samples. Columbia River waters were within State of Washington water quality standards, with the exception of pH and fecal coliform bacteria. These latter contaminants are not attributable to Hanford Site activities.

Measured and calculated doses to the population living within 50 miles of the Site, estimated for 1987 was 4 person-rem, compared with 9 person-rem estimated for 1986. These doses can be compared with the 300 millirem and 100,000 person-rem received annually by an average individual and by the surrounding population, respectively, as a result of naturally occurring radiation.

Well Construction Information for 200-West Area Wells(a)

Well Number (data base number)	Coordinates	Casing Elevation, ft/MSL	Drill Depth, ft	Depth to Water, ft (b)	Depth to Bottom, ft	Screen Interval, ft	Hydrogeologic Unit	Date Completed
299-U6-2 (2692)	N 45571 W 75302	692.45	248.0	230.47	245	225 to 245	Middle Ringold	11-13-87
299-U7-1 (2686)	N 46551 W 78601	690.71	245.0	228.61	244	224 to 244	Middle Ringold	7-30-87
299-U7-2 (2687)	N 46519 W 77385	675.59	236.0	214.48	222	202 to 222	Middle Ringold	9-30-87
299-U7-3 (2688)	N 46520 W 77420	676.14	475.0	216.28	470	449 to 470	Middle/basal Ringold	11-23-87
299-U7-4 (2689)	N 45435 W 77040	671.69	235.0	208.35	233	203 to 233	Middle Ringold	11-19-87
299-U7-5 (2690)	N 46509 W 76816	673.03(c)	229.0	210.51	228	208 to 228	Middle Ringold	11-19-87
299-U7-6 (2691)	N 46509 W 76219	678.64	243.0	218.03	229	209 to 229	Middle Ringold	11-2-87
299-U8-1 (2676)	N 46551 W 79200	701.33	270.5	238.82	256	236 to 256	Middle Ringold	7-23-87
299-U9-1 (2685)	N 44508 W 79507	737.73	295.0	272.09	286	266 to 286	Middle Ringold	10-22-87
299-U10-13 (2683)	N 43137 W 78297	699.04	250.0	232.11	247	227 to 247	Middle Ringold	9-25-87
299-U10-14 (2684)	N 43143 W 78330	699.43	462.0	232.90	447	427 to 447	Middle Ringold	11-18-87
299-U15-15 (2680)	N 40330 W 78103	697.96	255.0	228.32	253	223 to 253	Middle Ringold	9-2-87
299-U15-16 (2681)	N 40269 W 77387	684.89	243.5	214.51	238	208 to 238	Middle Ringold	9-2-87
299-U15-17 (2682)	N 40221 W 77387	684.64	450.0	214.71	432	422 to 432	Middle Ringold	10-28-87
299-U15-18 (2677)	N 39705 W 77383	685.71	242.5	214.81	238	208 to 238	Middle Ringold	8-4-87
299-U18-21 (2678)	N 37794 W 78080	668.62	227.0	198.54	226	196 to 226	Middle Ringold	7-29-87
299-U18-22 (2679)	N 37831 W 78109	668.49	445.0	199.17	447	416 to 447	Middle Ringold	9-25-87
299-U18-23 (2675)	N 38987 W 78120	696.81	255.0	226.74	251	221 to 251	Middle Ringold	7-1-87
299-U18-24 (2674)	N 38998 W 77180	684.35	240.0	213.14	235	205 to 235	Middle Ringold	8-11-87

(a) Diameter of all wells is 4 in.

(b) Depth to water measured from top of casing; all other measurements are from ground surface.

(c) 1.89 ft of casing were added between January 7 and January 14, 1988. Well has not been resurveyed.

MSL = Mean sea level.

FIGURE A5 - WELL CONSTRUCTION INFORMATION FOR 200 WEST AREA WELLS

FIGURE A6 - SCHEMATIC OF WELL DESIGN USED AROUND THE 200 WEST AREA LOW-LEVEL BURIAL GROUNDS

FIGURE A8 - LOCATION OF SURFACE WATER FEATURES, INCLUDING PONDS, DITCHES, AND PRINCIPLE DAMS

Climate, meteorology and Seismology of the Site:

The Hanford climate is arid and hot in the summer and cool in the winter. Rainfall averages 6.3 inches of precipitation per year and most of that is in the form of snow. Average temperatures are 35.6° F in January to 95° F in July. Record temperatures are 114.8° F and -27° F. The prevailing winds are from the Northwest and secondary maximum from the southwest. Winds are 6-7 mph in winter and 9-10 mph in summer. The 100 year extreme maximum wind is estimated to be 85 miles per hour. Tornado probabilities are small. Reference Figure A9.

The Columbia Plateau is in an area of moderate seismicity. Swarms of small, shallow earthquakes are the predominant seismic events with magnitudes of 1.0 to 3.5 on the Richter scale. Reference Figure A10.

FIGURE A9 - HANFORD SITE WIND ROSES, 1979 THROUGH 1982(STONE et al 1983). STATION 6 ARE MOST REPRESENTATIVE CONDITIONS IN THE 200 AREAS

FIGURE A10 - TECTONIC STRUCTURES ADJACENT TO THE 200 AREAS

Ecology:

The ecology of the Hanford Site is that of a cool desert or shrub steppe. Because of the arid climate, the productivity of both plants and animals is relatively low compared with that of other natural communities with higher rainfall.

The dominant plants on the Hanford Site are large sagebrush, rabbit-brush, cheatgrass, and Sandberg bluegrass. Cottonwoods, willows, cattails, and bulrushes grow along ponds and ditches. Cheatgrass and Russian thistle invade areas where the ground surface has been disturbed. More than 300 species of insects, 11 species of reptiles and amphibians, more than 125 species of birds, and 27 species of mammals are found on the Site. The Columbia River supports the most important aquatic ecosystem on the Site. Forty-five species of fish have been identified in the Hanford Reach.

Unavoidable Adverse Impacts Due to Decommissioning Reactors:

The proposed action is to decommission the eight surplus reactors. The purpose of decommissioning is to isolate securely any remaining radioactive or hazardous waste in a manner that will reduce environmental impacts to an acceptable level, especially potential health and safety impacts to the public.

Another adverse impact is dedication of land to the disposal of radioactive waste. The land required for radioactive waste disposal in the 200-Areas is about 6 hectares, which is offset by the 5 hectares that would become available for other DOE use in the 100 areas following removal or dismantlement of all eight reactors. For in situ decommissioning, however, about 20 hectares of land would be occupied in the 100 areas by the eight reactor mounds, although no land would be required in the 200 Areas for the radioactive-waste disposal.

Adverse environmental impacts that can be mitigated included occupational radiation doses, disruption to land areas, and migration of chemicals and radionuclides caused by water infiltration through waste-disposal sites. Sites used for acquisition of dirt and gravel will be surveyed for archaeological resources and endangered species, and will be rehabilitated when no more material need be acquired from the site.

Water migration through the waste-disposal sites (both the 200-West Area and the 100-Area sites) will be mitigated by the installation of a multi-layer, engineered barrier consisting of a capillary layer of fine-textured soil underlain by an impervious layer of soil/bentonite clay. Calculations in the DEIS are based on a water infiltration rate through the barrier of 0.03937 inches per year.

Environmental regulations and standards of potential relevance to decommissioning are those promulgated by the EPA under the Atomic Energy Act(AEA), the Clean Air Act (CAA), Clean Water Act(CWA), Safe Drinking Water Act(SDWA), Resource Conservation and Recovery Act(RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act(CERCLA). State environmental regulations have also been promulgated under the authority of some of these federal statutes. Regulations of the U.S. Nuclear Regulatory Commission do not apply to the decommissioning of the surplus production reactors.

No EPA permit is expected to be required for decommissioning purposes, with the possible exception of a RCRA permit. No existing EPA standard is expected to be exceeded either by decommissioning operations or by disposal actions.

Hanford Waste in 200 West Area:

Hanford waste that has been buried in other sites may possibly be buried in the W-025 trench. Waste was considered low-level for our design but the exact type of waste was not provided to our design team. Waste received between 1968 and Dec 31, 1987 as well as specific waste buried in areas within the 200 West Area are included. See the following Figures A11 and A12.

Solid Radioactive-Mixed Waste Received
Between 1968 and December 31, 1987

Acetonitrile	Lead pies
Acid	Lithium fluoride
Aliquat 336	Mercury
Aluminum nitrate	Methanol
Amalgamated mercury	Napthlamine tritium
Anase	Napthyalene
Antifreeze	Nitrate
Asbestos	Nitric acid
Barium	Normal paraffin hydro
Batteries	Oil
Beryllium	Organic
Beryllium zinc	Polychlorinated biphenyls
Beryllium zirconium	Polychlorinated biphenyl, oil
Butyl acetate	Paint thinner
Cadmium	Perchloroethylene
Carbon tetrachloride	Phosphoric acid
Carcinogens	Polyurethane
Caustic	Potassium chloride
Charcoal	Potassium nitrate
Chromium	Psuedocumene
Copper	Silver
Copper sulfate	Silver nitrate
Corrosive	Slaked lime
Cortisporin	Sodium
Creosote	Sodium chloride
Cyclohexane	Sodium diuranate
Cyclohexanone	Sodium fluoride
DDCP	Sodium hydroxide
Dibutyl phosphate	Sodium nitrate
Dioxane	Solvents
Ethanol	Sulfuric acid
Ethanolamine	Tar
Ethylene glycol	Toluene
Freon 12	Tributyl phosphate
Freon II	Trichlorethane
Glycerine	Tricloreethylene
Hexane	Trioctyl phosphine 0
Hexanol	Tetrahydrofuran
Isopropanol	Uranium hexafluoride
Isopropyl alcohol	Vinyl chloride
Kerosene	Xylene
Lead	Xylene/psuedocumene
Lead brick	Xylene/toluene
Lead cadmium	Zirconium
Lead shielding	

**FIGURE A11 - SOLID RADIOACTIVE-MIXED WASTE RECEIVED BETWEEN 1968
AND DEC. 31, 1987**

Hazardous Constituents Disposed to Burial Grounds 218-W-3A, 218-W-3A-E, and 218-W-5 Prior to December 31, 1987. Taken from the SWIMS^(a) data base.

<u>Burial Ground 218-W-3A</u>		<u>Burial Ground 218-W-3A-E</u>
Acetonitrile	Napthyalene	Aluminum nitrate
Aliquat 336	Nitric acid	Asbestos
Amalgamated mercury	Normal paraffin hydro	Beryllium
Anase	Oil	Beryllium zirconium
Asbestos	Organic	Carcinogens
Barium	Phosphoric acid	Charcoal
Batteries	Polyurethane	Chromium
Beryllium	Psuedocumene	Copper
Beryllium zinc	Silver	Freon II
Butyl acetate	Silver nitrate	Lead
Cadmium	Slaked lime	Lead brick
Carbon tetrachloride	Sodium	Lead pies
Carcinogens	Sodium hydroxide	Lead shielding
Caustic	Solvents	Mercury
Charcoal	Tar	Nitrate
Chromium	Toluene	Oil
Copper	Tributyl phosphate	Polychlorinated
Cortisporin	Triclorethylene	biphenyls, oil
Cyclohexane	Trioctyl phosphine 0	Perchloroethylene
Cylcohexanone	Tetrahydrofuran	Potassium chloride
DDCP	Uranium hexafluoride	Potassium nitrate
Dibutyl phosphate	Xylene	Silver
Dioxane	Xylene/psuedocumene	Sodium chloride
Ethanol	Xylene/toluene	Sodium fluoride
Ethanolamine	Zirconium	Sodium hydroxide
Ethylene glycol		Sodium nitrate
Freon II		Sulfuric acid
Glycerine		Tar
Hexane		Trichlorethene
Hexanol		Zirconium
Isopropanol		
Isopropyl alcohol		<u>Burial Ground 218-W-5</u>
Kerosene		Charcoal
Lead		Lead
Lead brick		Lead brick
Lead cadmium		Lead shielding
Lead shielding		Oil
Lithium fluoride		Slaked lime
Mercury		
Methanol		
Napthlamine tritium		

(a) Solid Waste Information Management System.

**FIGURE A12 - HAZARDOUS CONSTITUENTS DISPOSED TO BURIAL GROUNDS
IN 200 WEST AREA PRIOR TO DECEMBER 31, 1987**

APPENDIX E

**"RECOMMENDATIONS FOR
INSTALLING CLAYMAX 500SP"**

**"CONCLUSIONS FOR EVALUATING
CLAYMAX 500SP AND BENTOMAT SS GCLS"**

**"EXPERIMENTAL RESULTS FOR EVALUATING
CLAYMAX 500SP AND BENTOMAT SS GCLS"**

RECOMMENDATIONS FOR INSTALLING CLAYMAX 500SP GCL

- o The Secondary Cover Design includes a Geosynthetic Clay Liner. The selected GCL was Claymax 500SP. Liner installation shall not begin until a proper subbase has been prepared to accept the bentonite liner. Unless otherwise required by the contract specifications and drawings, the prepared surface shall be free from loose earth, fully exposed rocks larger than 1/2 inch in diameter, rubble and other foreign matter. The subgrade shall be uniformly compacted to a minimum of 90% modified proctor density (ASTM D1557), to ensure against settlement and rutting under wheel loads and shall be smoothed with a smooth drum or vibratory roller. Field Density tests shall be made using either ASTM D2922 or D1556 at a frequency of one per acre to verify the compaction of the subgrade.
- o During of installation of Claymax 500SP, installers must prevent Claymax from getting wet. Also, months of rain or wet periods must be avoided. The base layer must have all rocks 3/4 inch diameter or greater removed. The adjacent soils in contact with Claymax should be compacted and prepared to create a smooth surface free of large voids and protrusions. Sand or rounded gravel with a large fines content is ideal so the Hanford site's surrounding materials will be adequate. Tears made in the Claymax, can be repaired by a Claymax patch at least 6 inches on each side of the tear with aggregate bentonite added at the seams. Bentonite paste will be used around insertion of venting pipes. Only as much Claymax that can be covered in a day should be laid. Once wet, driving equipment over the layer is not recommended. Claymax should not be installed in standing water or rain. Do not install on a porous subgrade. When installing Claymax liner, all seams on slopes must be perpendicular to the excavation bottom. This method prevents seam displacement during the backfill procedure. It is also important that the first Claymax liner roll and all succeeding rolls be pulled tight to smooth out creases.
- o The Claymax liner must be installed with the stenciled polypropylene side up (facing the operator). The polypropylene protects and supports the system on installation. The liner can either be pulled from a roll suspended at the top of a slope, or the free end may first be secured in a locking trench and the suspended roll can be backed down the slope and across the excavation by the supporting vehicle.
- o The enclosure should be determined to allow for a final addition of a minimum 6-8 inches of soil or aggregate cover material. The excavation should be will contoured with slopes that are at a maximum of three-to-one. Protrusions and rocks larger than 2 inches in diameter should be removed and the entire excavation should be compacted sufficiently to prevent ruts from installations vehicles. Compaction can be accomplished using either conventional rolling equipment or wheeled vehicles. Use of sheepfoot rolling equipment is not recommended. A liner locking trench (min. 18 inches deep) must be provided at the top of all slopes.
- o At no time shall the Claymax rolls be dragged over the surface, except for slight shifting necessary for the adjustment of the overlap, or allowed to roll down the slope.
- o In areas where wind is prevalent, Claymax liner installation should be started at the upwind side of the project and proceed downwind. The leading edge of the liner shall be secured at all times with sandbags or other means sufficient to hold it down during high winds.
- o Once the first run has been laid (stenciled "Claymax" side down), adjoining runs shall be laid (stenciled "Claymax" side down) with a six to twelve inch minimum overlap on project specifications. Six inch and twelve inch overlap lines have been marked on the liner to assist in obtaining the proper overlap. All dirt, gravel or other debris shall be removed from the overlap area of the mat. If required by project specifications, a bead of non-toxic, water soluble adhesive, can be applied between the overlapped panels to ensure that the joints will not be displaced during the cover operation.
- o On slopes, all runs shall be continuous from crest to toe with the Claymax machine direction running perpendicular to the base.
- o In hot, arid conditions, when temperatures are higher than 85 degrees F and humidity is low, shrinkage may occur soon after placement when no confining stress or soil cover is placed. In order to account for the

possibility of shrinkage under these conditions, the longitudinal seam overlap shall be increased to twelve inches and all other seams increased to 4% of the distance to the closest parallel seam. (For example, on the panel end seams 13 ft long seams spaced on 100 ft centers the seam overlap shall be $4\% \times 100 \text{ ft} = 48$ inches.)

- o To prevent premature hydration or shrinkage in hot conditions, only the amount of Claymax that can be anchored, inspected, repaired and covered in the same day shall be installed.
- o Pipe penetrations shall incorporate a collar of Claymax wrapped around the pipe and securely fastened. Claymax sealing compound shall be placed around the corners for additional protection. An additional Claymax skirt placed over the Claymax sealing compound is also recommended to provide a third level of protection and prevent the bentonite mastic from being displaced as shown on the Engineer's contract drawings.
- o Regardless of the nature of the cover material used, the HDPE liner should be placed as soon as possible after the GCL has been deployed. The efforts of placing the HDPE and placing the final cover should be coordinated to the extent that only as much GCL as can be covered should be deployed in one working day. This will prevent premature hydration and will greatly reduce the chances for incidental damage to the GCL during other activities.
- o In addition to particle size, the angularity of a crushed stone or gravel will impact the construction survivability of the GCL. It is preferred that relatively rounded materials be utilized.
- o With respect to the equipment used to place the protective cover, it is strongly recommended that no heavy equipment come in direct contact with the Claymax 500SP GCL. Obviously, tracked equipment will damage the liner. In some cases, however it is necessary to drive equipment directly in the Bentomat. This can be accomplished with low-pressure, rubber-tired equipment. Permission to do so will be granted by the Products Company through the CQA engineer on a case-by-case basis only and will include restrictions on the equipment itself and on the type of movements the vehicle may make on the Claymax 500SP.
- o Our design incorporates putting a HDPE geomembrane liner system component placed over Claymax 500SP. Caution must be used during this activity so as not to damage the Claymax 500SP. Again, it is strongly recommended that no heavy equipment come in direct contact with the Claymax 500SP. Exceptions will be made on a project-specific basis.
- o A special precaution should be taken when textured geomembrane is installed directly over the Claymax 500SP in a composite liner system. Because of the considerable friction between the geomembrane and the Claymax 500SP, it is difficult to pull the geomembrane over the Claymax 500SP and into position for welding to adjacent sheets. Excessive pulling on the geomembrane can damage the needlepunched fibers on the surface of the Claymax 500SP. This damage should be prevented by the use of a smooth "slip sheet" to provide a low-friction sliding surface for the geomembrane until it is in position for welding.
- o For needle-punched GCL's, add granular bentonite to the overlapped areas at a rate of 1/4 lb per linear foot.
- o Face the non-woven or secondary woven carrier geotextile against soil or geotextile filter fabric.
- o On side slopes, run Claymax 500SP to the bottom of the slope as indicated.

Overlaps:

- o On slopes, overlap Claymax 500SP to the manufacturer's match line.
- o In general, no horizontal seams are allowed on side slopes.
- o For needle-punched GCL's, apply granular bentonite to overlapped area at a rate required by the manufacturer.

Defects and Repairs:

- o Repair all flaws or damaged areas by placing a patch of the same material extending at least 1 foot beyond the flaw or damaged area.
- o For needle-punched Claymax 500SP's, add granular to the overlapped edges of the patch at rate of 1/4 lb per linear foot.

INTRODUCTION TO CLAYMAX 500SP and BENTOMAT SS:

This Appendix includes the evaluation of the Claymax 500SP and Bentomat SS Geosynthetic Clay Liners (GCL's). Much of the information was derived from a thesis called "The Potential Use of Geosynthetic Clay Liners as Final Covers in Arid Regions", written by Brian Thomas Boardman, University of Texas, May 1993. The research from this thesis and other readings were used in the evaluation of these two GCL's with our selection being Claymax 500SP, manufactured by the James Clem Corporation. The Handford Environment is relatively arid at 6.3 inches of precipitation per year.

The conclusions of the evaluation and followed by the detailed experimental results are the two primary sections of this appendix. A material description of Bentomat SS follows.

CONCLUSIONS FOR EVALUATING CLAYMAX 500SP AND BENTOMAT GCLs:

Product research was conducted by Brian Boardman in a thesis (May 1993) at the University of Texas at Austin. His research was to determine the effect of differential settlement and desiccation on the short and long term hydraulic conductivity of large scale (32 square ft) GCL samples. An overlap of 9 inches was used. Four commercially available materials were studied: Bentomat SS, Claymax 200R, Claymax 500SP and Gundseal. All are discussed here except Gundseal.

Tests were carried out under controlled laboratory conditions. Because testing conditions directly affect the hydraulic conductivity of a GCL, the testing conditions used in this study should be carefully reviewed before applying the results of this study to an actual site. Tests were conducted in large, rectangular, steel tanks on GCL samples measuring 8 feet long and 4 feet wide. Once installed in the tank, each GCL was covered with two feet of gravel to simulate the expected normal stress in a typical final cover system. Samples were permeated with water under a hydraulic gradient of 25 and an effective stress of 1.1 psi.

Based on some of the results of this study, a few conclusions are drawn:

The Bentomat SS and Claymax 500SP GCL's demonstrated the ability to attain a steady low value of hydraulic conductivity when the GCL's were subjected to a large distortion equal to ($\epsilon/L=0.33$) prior to being hydrated. Both the Bentomat SS and Claymax 500SP GCL's are internally reinforced. This internal reinforcement may have prevented the movement of bentonite within each GCL as the bentonite initially hydrated, which would help the deformed GCL to maintain a low value of hydraulic conductivity. The hydraulic conductivity of an overlapping sample of Bentomat SS appeared to be dependent on the degree of hydration of the loose bentonite seam along the overlap.

The Claymax 200R, Claymax 500SP and the Bentomat SS product were all researched but the properties of the Claymax 200R are assumed to be contained within the Claymax 500SP product. However, the Claymax 500SP has needle punched fibers and a stronger lower geotextile allowing it to perform better on steeper slopes along with additional strengths.

The needle punched Claymax 500SP has stronger more dense fibers in its lower geotextile than the Claymax 200R product which allows it to withstand large distortion and still provide good performance as a GCL. Prior to rehydration of the Claymax GCLs, the top geotextile for both Claymax products will bridge over depressions. The Claymax 200R may have a weaker lower geotextile which allows some "flow through" but the Claymax 500SP will remedy this problem. The Claymax 500SP has a stronger lower geotextile which will conform to the distortion but confines the bentonite on its lower side so the GCL can hydrate and expand without high rates of

flow. Further study revealed that there was no appearance that the long term hydraulic conductivity of the Bentomat and the Claymax 200R is dependent on whether or not the GCLs are hydrated when the differential settlement occurs.

The unreinforced Claymax 200R GCL demonstrated the ability to reswell and self seal after a single wetting and drying cycle. The level of flow through both intact and overlapping samples of Claymax 200R was very high when the desiccated samples were initially hydrated, but flow slowly decreased as the cracked bentonite within the samples began to absorb water and reswell. The long term, steady value of hydraulic conductivity for both samples was essentially the same before and after the single desiccation cycle. The Claymax 500SP may have similar results, if not better, due to its internal stitching. The Claymax 500SP will be similar to the Bentomat SS but with better conductivity values and the ability to achieve higher water contents if leakage from the above liners does occur.

The Bentomat SS GCL demonstrated the ability to withstand a single wetting and drying cycle as there was little to no flow through both intact and overlapping samples when the desiccated samples were initially hydrated. Perhaps the internal reinforcement of the Bentomat SS GCL restricted the bentonite within each sample from shrinking and cracking as it dried out.

In conclusion, problems with Compacted Clay Liners(CCLs) within a final cover system can possibly be replaced by a Geosynthetic Clay Liner(GCL) which protects and holds the desiccated bentonite within the geotextile liner in areas of arid regions. The research conducted on the GCLs mentioned above dealt with their performance when being deformed prior to hydration or subjected to a single wetting or drying cycle. These are the potential problems associated within a final cover at an arid site. Further research may have to be done but the use of the Claymax 500SP GCL at the Hanford Site should work well. This takes into consideration the 6.3 inches precipitation per year, being directly covered by an HDPE, and being directly laid upon a compacted sand/silt/soil bed. If a GCL is used by the Hanford Corporation, field tests from other final covers from environmentally similar sites should be obtained.

EXPERIMENTAL RESULTS FOR ANALYZING BENTOMAT SS AND CLAYMAX 500SP

The experimental results were taken from large scale, constant head, hydraulic conductivity tests on GCLs subjected to either a large distortion prior to a single wetting and drying cycle. Both overlapped samples and continuous intact samples were used. The experimental results are broken up into a Differential Settlement Study and a Desiccation Study.

Differential Settlement Study:

The purpose of a "Differential Settlement Study" was to determine the effect of a large distortion ($(\Delta / L) = 0.33$) on the hydraulic conductivity of a GCL. The GCL was distorted by inducing a large differential settlement beneath the sample "prior" to hydration. The sample was then permeated with water for a period of one to two months to determine if the deformed GCL could attain a steady, low value of hydraulic conductivity. The Bentomat SS and the Claymax 500SP are discussed below. Overlapped samples and Intact(continuous) samples were tested and discussed, followed by the assessment of the study for each product. The Claymax 200R provided additional experimental results but were incorporated in with the Claymax 500SP where applicable.

Bentomat SS (Overlapped Sample):

When the sample was initially hydrated, flow occurred immediately through the deformed GCL. As the loose bentonite along the overlap hydrated and swelled, the hydraulic conductivity slowly dropped from its initial peak of 2×10^{-6} cm/s. After a month of permeation, the hydraulic conductivity reached a steady stage value of approximately 7×10^{-8} cm/s.

After the GCL was inspected, the loose bentonite seam, placed along the centerline of the overlaps was fully hydrated and intact. The highest measured water content and thickness of the GCL(193% and 0.6 in.) were found in the lower mat, beneath the overlap, and in the center of the depression. The average values around the perimeter of the depression were 151% and 0.4 in.

Bentomat SS (Intact Sample):

Flow occurred through the sample two months after the initial hydration of the deformed GCL. The hydraulic conductivity reached an approximate value of 3×10^{-9} cm/s after three months of permeation. The average thickness of the deformed GCL was 0.5 inch. The highest water contents (235% to 245%) of the GCL were found down the centerline of the depression.

Assessment of the Performance of Bentomat SS:

Although the overlapping sample did not perform as well as a hydraulic barrier when compared to the intact sample, the overlapping sample did maintain a long term hydraulic conductivity that was slightly less than 1×10^{-7} cm/s. When both samples were initially hydrated, flow occurred immediately through the overlapped sample, while it took over two months for the flow to occur through the intact sample. The initially high flow rates through the overlapping sample were most likely the result of water flowing relatively freely across the overlap. It is assumed that as the loose bentonite seam along the overlap slowly hydrated, the hydraulic conductivity of the GCL decreased. Thus, the hydraulic performance of the Bentomat SS GCL appears to be governed primarily by the effectiveness of the overlap when the GCL is deformed prior to being hydrated.

Claymax 500SP (Overlapped Sample):

Flow occurred through the sample one month after initial hydration of the deformed GCL. The hydraulic conductivity reached an approximate value of 9×10^{-9} cm/s after two months of permeation. The overlapped mats appeared to have self-sealed along the overlap through several different mechanisms, similar to that of the Claymax 200R. First, hydrated bentonite oozed out of the edge of the upper mat and had formed a seal along the upper line of contact between the two mats. Second, the thickness of the upper mat increased where contact with the lower mat ceased(almost as if the upper mat had swelled around the lower mat when both mats were hydrated). Third, bentonite had oozed out the edge of the lower mat and had molded into the overlying mat along the lower line of contact. Due to the Claymax 500SP, oozing of the bentonite at the seams should be slightly less due to the stitching.

The highest water content (321% to 353%) and thickness(0.6 in) of the GCL were found along both the upper and lower lines of contact between the two mats. The higher water contents (approx. 270%) of the GCL were found on the top mat, down the centerline of the depression. The Claymax 200R had as much as 600-700% water content.

Claymax 500SP (Intact Sample):

Flow occurred through the sample five weeks after the initial hydration of the deformed GCL. The hydraulic conductivity slowly rose to a steady value of 6×10^{-9} cm/s after three weeks of permeation. After breaking down the test, the higher water contents and thicknesses of the GCL were found down the centerline of the depression (average values of 327% and 0.75 in.).

Assessment of Performance of Claymax 500SP:

Both the intact and overlapped samples maintained a very low hydraulic conductivity ($< 1 \times 10^{-8}$ cm/s) when the GCLs were deformed prior to being hydrated. The steady state hydraulic conductivity and time for flow to occur through the GCLs was essentially the same for intact and overlapped samples. Either the needle stitching or the increased stiffness of the lower geotextile allowed the intact sample of Claymax 500SP to attain a lower hydraulic conductivity after deformation than the intact sample of Claymax 200R.

Desiccation Study:

The purpose of this study was to determine the effect of one wetting and drying cycle on the hydraulic conductivity of a GCL. A GCL was permeated with water for several weeks, then dried out using a system of

heated air blowers and vacuum pumps. When in-situ water content readings indicated that the GCL was dry, the sample was again slowly monitored to determine the ability of the desiccated GCL to rehydrate and self seal.

Bentomat SS (Overlapped Sample):

The hydraulic conductivity of the overlapped sample prior to being dried out was assumed to be equal to 1×10^{-9} cm/s based on values found by LaGatta (1992). There was flow through the GCL immediately after the sample was first hydrated. The sample was permeated for three weeks, but steady state conditions were not reached. The loose bentonite seam placed along the overlap was hydrated (water content of 163%), and intact. Water contents taken across the centerline of the sample averaged 203%.

Bentomat SS (Intact Sample):

The sample was permeated for three weeks, but no outflow occurred. Water contents taken across the centerline of the sample averaged 206%.

Assessment of the Performance of Bentomat SS:

Both the intact and overlapping samples demonstrated the ability to maintain a relatively low value of hydraulic conductivity (1×10^{-9} cm/s prior to desiccation) after being subjected to a single desiccation cycle. It is possible that the internal reinforcement of the Bentomat SS GCL restricted the bentonite within each sample from shrinking and cracking as it dried out. As the width of the overlap was still 9 in. after the completion of the test, a single desiccation cycle did not cause any irreversible shrinkage to occur along the overlap when the GCL was dried out under a normal stress of 200 psf.

Assessment of the Performance of Claymax 500SP

Desiccation tests were not performed on the Claymax 500SP GCL. One could speculate that the behavior of the Claymax 500SP would be similar to the behavior of the Claymax 200R GCL, while the effect of needle-stitching on the ability of a desiccated GCL to rehydrate and self seal is assumed to be equivalent or better than the Bentomat. This is due to the Claymax 200R product having both the intact and overlapped samples demonstrating the ability to reswell and self seal after one desiccation cycle. The hydraulic conductivity of the GCL's was initially very high (7×10^{-9} cm/s prior to being dried out) as the desiccated samples were rehydrated. The level of flow through the samples slowly decreased as the cracked bentonite within the desiccated GCL's began to absorb water and reswell. There was a slight increase in the long term, steady state hydraulic conductivity of the intact sample; however, the hydraulic conductivity of the overlapped sample remained essentially the same. The 200R achieved higher water contents (334%) and swelled to 0.6 inches.

General GCL Product Information:

Bentomat SS- Information:

Bentomat is manufactured by the Colloid Environmental Technology Company (CETCO), a subsidiary of the American Colloid Company. The Bentomat GCL is produced by needle-punching loose, granular sodium bentonite between two polypropylene geotextiles.

The lower geotextile is typically non-woven, while the upper geotextile can be woven or non-woven. The geotextiles usually weigh between 3 to 6 oz/square yard. Both the weights and the types (woven versus non-woven) of geotextiles can be varied by the manufacturer depending on the needs of the project.

Bentomat is needle-punched with thin, polypropylene fibers that hold the loose bentonite in place during installation. After hydration, the bentonite swells around the impermeable fibers to form a uniform hydraulic barrier. Needle-punching also increases the internal shear strength of the GCL (Shan, 1991). However, the long term transmission of shear loads on the needle-punched fibers remains questionable and has not been studied to date (Daniel and Boardman, 1992).

The manufacturers place approximately 1 lb/square foot of a proprietary, loose, granular bentonite known as Volclay into the GCL. The dry clay typically has a water content between 10 to 12%, and can be treated if necessary. Various materials can be added to the Volclay to improve the GCL's swelling properties or to increase the ability of the GCL to resist chemical alterations.

Bentomat typically comes in rolls that are 12 feet wide by 100 feet long. An overlap of 6 to 9 inches is recommended by the manufacturer. The manufacturer also recommends that approximately 0.25 lb/ft of loose, dry bentonite be placed along the centerline of the overlap in order to form a better edge seal between the overlapping GCL rolls when hydration takes place

The SS Volclay, along with a 3 ounce woven upper geotextile and a 6 ounce non-woven lower geotextile was used in the Bentomat for this study.

Claymax 500SP

The Claymax 500SP is discussed in the Materials Description Sections.