TECHNICAL MEMORANDUM

To: Office of Site Remediation and Restoration (OSRR)

From: Dennis P. Gagne, Chief
Technical Support and Site Assessment
Yoon-Jean Choi, P.E., Geotechnical Engineer
Technical Support and Site Assessment

Subject: Revised Alternative Cap Design Guidance Proposed for Unlined, Hazardous Waste Landfills in the EPA Region I

Date: February 5, 2001

The purpose of this technical memorandum is to provide guidance to the designer of a cover or cap system for unlined, hazardous waste landfills at Superfund landfill sites in New England[1]. It is also intended to be a source of technical information for regulatory personnel (e.g., RPMs, RFMs, ...) to assist them in evaluating cap designs submitted for approval[2].

Landfill caps at Superfund sites should meet the RCRA technical requirements contained in 40 CFR 264.310. The regulatory requirements of the above referenced section specify that final covers must be designed and constructed to:

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

(2) Function with minimum maintenance.

(3) Promote drainage and minimize erosion or abrasion of the cover.

---

[1]Depending on the contaminants within a landfill (PCBs, asbestos, and other waste exempt from RCRA) other federal or state capping standards, such as those under the Toxic Substances Control Act (TSCA), 15 U.S.C. §§ 2601, et seq., may apply rather than the RCRA standards discussed in this guidance.

[2]This technical document takes into consideration regional and site specific conditions that are not effectively addressed by the national guidance. The guidance is presented as an alternative that is considered appropriate and acceptable to Region 1. It is not intended to replace the national guidance or eliminate other alternatives. The alternative guidance has been provided to EPA's remedial project managers and other interested parties for their use in the design of landfill covers and for evaluating their effectiveness.

(4) Accommodate settling and subsidence so that the cover's integrity is maintained.

(5) Have a permeability less than or equal to permeability of any bottom liner system or natural subsoils present.

The majority of Superfund landfill sites do not have engineered bottom liners. Therefore, following the requirements of 40 CFR 264.310(a)(5), a cap for this type of facility could be designed and constructed with relatively permeable materials. However, though 40 CFR 264.310(a)(5) allows a more permeable design, we believe that more effective long term minimization of rainwater infiltration through the closed landfill would be provided by the cap design recommended in EPA guidance (EPA Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments; EPA/530-SW-89-047, July 1989). The cap design recommended in this document satisfies the requirements of 40 CFR 264 and 265 Subparts G (closure and post closure), K (surface impoundments) and N (landfills). The EPA recognizes that other cap designs may be acceptable, depending on site specific conditions and a determination by the Agency that the alternative design adequately fulfills the regulatory requirements. Such an alternative design is proposed in the following attachment.

The alternative cap design proposed consists of drainage geocomposite, geomembrane and 10^{-4} cm/sec soil (or geosynthetic clay liner only on top flat areas). An evaluation of this alternative cap using the EPA HELP model shows that it can provide equal or better performance minimizing the infiltration of rainwater (and the resultant leachate generation) than an EPA cap recommended to meet the requirements of RCRA Subtitle C.

Dennis Gagne (617-918-1431) and Yoon-Jean Choi (617-918-1437) of OSRR took the lead in developing this guidance. Please contact them should you need assistance in implementation of the proposed landfill cap design.

Table of Contents
Revised Alternative Cap Design Guidance
Proposed for Unlined, Hazardous Waste Landfills
in the EPA Region 1

February 5, 2001

ALTERNATIVE CAP DESIGN GUIDANCE PROPOSED FOR UNLINED[3], HAZARDOUS WASTE[4] LANDFILLS IN THE EPA REGION I

When designing landfill cap systems, the primary objectives are to 1) limit the infiltration of rainwater to the waste so as to minimize generation of leachate that could possibly escape to ground-water sources, 2) ensure controlled removal of the landfill gas, and 3) provide the foundation for an aesthetic landscape and allow vegetation of the site (or restore the site to the required beneficial afteruse).

I. CAP COMPONENTS

To protect the environment and prevent harm to human health, the EPA Region I recommends that a landfill cap consist of the following (from bottom to top):

1. Base (Leveling) Layer: Forms a base for the capping construction.

- Minimum thickness of fill materials should be 6 inches (15 cm) to establish the rough grading of the cap.

2. Gas Vent Layer (Optional): Based on site-specific basis, the passive gas vent layer (or systems) should be able to control the volume of gas that may be formed during anaerobic decomposition of the waste.

- The gas vent layer should be placed below the low-permeability layer (i.e., geomembrane and low-permeability soil) to facilitate the control and collection of landfill gasses.

- Minimum 12 inches (30 cm) of sand and/or gravel with a permeability greater than 0.01 cm/sec is required to allow free movement of gasses trapped by the low-permeability layer and to protect the structural integrity of the cap from the uplifting forces due to the gas pressure.

- Where gravel or sand (i.e., gas vent layer) is covered by a compacted, low-permeability soil layer, a geosynthetic filter layer may be placed at the interface to separate the two layers.

- Geosynthetic materials (e.g., geocomposite) may be substituted for sand or gravel in the gas vent layer if they can provide sufficient gas transmissivity and structural stability under the anticipated field conditions for the projected design life.

---

[3] For abandoned landfill sites without a barrier layer at the base

[4] Resource Conservation and Recovery Act's (RCRA) Subtitle C regulates hazardous wastes that exhibit one or more of the following characteristics: Ignitability, Corrosivity, Reactivity, or EP Toxicity or which are listed hazardous wastes under 40 CFR 261.30.

The vertical outlet gas vents or pipes for passive systems need to be located at the highest elevation of the gas vent layer to allow maximum evacuation of the gas. In unlined landfills, the gas vent outlets should penetrate to the bottom of the waste or extend to the top of the ground-water to assist in reducing the possibility of gasses migrating laterally.

3. Bottom Low-Permeability Soil Layer: The purpose of this layer is to provide a second level of protection against infiltration in the event that the top low-permeability layer (geomembrane layer) has a leak. The EPA[5] recommends a low permeability soil (i.e., compacted clay) with a permeability of 1×10^{-7} cm/sec or less, but complicating factors such as potential placement problems, desiccation crack development, low shear strength when wet, and borrow source availability, in most cases preclude the use of these materials for landfill covers in EPA Region I. Historical evidence suggests that the identification of a low-permeability soil layer borrow source that has adequate interface friction resistance with the geomembrane, as well as permeability less than 1×10^{-5} cm/sec may not be practical.

The integrity of a compacted clay cap can also be affected, over time, by differential settlement which can disrupt the cap structure and impair its performance. In New England, at least four clay caps constructed in compliance with state closure requirements have experienced extensive damages within compacted clays. Field investigations of existing clay caps have shown in-situ permeabilities in the range of 1×10^{-3} cm/sec to 1×10^{-5} cm/sec instead of 1×10^{-7} cm/sec achieved at the time of installation and required by the design specifications. For the reasons stated in the previous paragraph it appears maintaining the required permeability of 1×10^{-7} cm/sec may not be sustainable except for a short period following its installation. However, based on the HELP model evaluation discussed in Section II: Evaluation of Alternative Caps, the assessment of cap designs using data for locally available silt and sand materials (with a permeability of 1×10^{-4} cm/sec) in combination with a geocomposite drainage layer (with a permeability of 10 cm/sec) and the geomembrane can yield results that exceed the hydrologic performance of the EPA-recommended cap design[5]. In addition, using the locally available material will yield substantial cost savings, remain more impermeable than clays, and could result in easier construction and greater cap slope stability.

The soil should be at least 12 inches (30 cm) of compacted, low-permeability materials with a permeability no greater than 1×10^{-4} cm/sec.

The last lift of the compacted, low-permeability soil layer beneath the geomembrane should contain no stones, larger than ½ inch, that may damage the geomembrane.

The upper surface of the compacted soil which is in contact with the geomembrane should have

[5] The EPA Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments (EPA/530-SW-89-047, July 1989)

a minimum slope of 3 percent after allowance for settlement.

The use of a Geosynthetic Clay Liner[6] (GCL) may also be a good alternative to low-permeability soil layer for cover systems due to its very low permeability when fully hydrated. Composite layers consisting of a geomembrane and GCL can be considered the ideal cover system in many conditions such as compliance with total and differential settlement, easy construction and quality control and cost efficiency. However, some aspects of GCL's long-term performance are questionable. These include its vulnerability to puncture and rips, long-term durability to dry/wet and freeze/thaw (e.g., chemical changes of bentonite), aging of the reinforcing fibers, long-term behavior related to the frictional characteristics of the interface on steep side slopes and the efficiency of the composite action if GCL incorporates an overlying geotextile. Thus the following should be met if a GCL is used.

- A reinforced geosynthetic clay liner (GCL) may be used on top flat areas with slopes less than or equal to six (Horizontal): one (Vertical) instead of using a compacted, low-permeability soil. The interface friction angle between the GCL and geomembrane can be very low, particularly when the GCL becomes hydrated, so that this material is recommended for use only in relatively flat areas to ensure cap slope stability. All joints should have a minimum overlap of 12 inches (30 cm) to provide a watertight connection and allow a sufficient factor of safety.

4. Top Low-Permeability Layer (Geomembrane: GM): Geomembranes are thin sheets of flexible, relatively impermeable (typical permeability values are in the range of 5×10^{-11} to 5×10^{-14} cm/sec), polymeric materials whose primary function is to act as a fluid (liquid and gas) barrier. They are increasingly used in landfill cover applications due to the fact that the geomembrane plays a primary role in limiting infiltration through the composite cap system.

The EPA[5] recommends a minimum thickness of 20 mils (0.02 inch or 0.5 mm), but 20 mils may not be a sufficient thickness for most geomembrane materials. Thicker geomembranes are better able to resist chemical aggression, temperature changes and gradients, stress corrosion and cracking, etcetera. Quality control and quality assurance (guideline for long term geomembrane welding performance at landfill sites is included in Appendix A) are of primary importance during geomembrane installation to guarantee satisfactory long-term performance of geomembranes since maintenance and remediation of the geomembrane is difficult once installed. For example, the minimum thickness of high density polyethylene (HDPE) geomembrane specified in Technical Regulations for Hazardous Waste issued by the German Federal Government is 100 mils (0.1 inch or 2.5 mm) assuming that the waste is thoroughly compacted (or controlled) prior to capping. In this case the stress due to the remaining differential

---

[6]Geosynthetic clay liners (GCLs) used in landfill cap applications are thin (approximately 1/4-inch thick) "blankets" of bentonite sandwiched between woven and non-woven geotextiles that are needle-punched (i.e., reinforced) together. Laboratory permeability test results of GCLs indicate a very low permeability of 1×10^{-8} cm/sec to 5×10^{-9} cm/sec when fully hydrated.

settlement is limited. Where there is a high potential for significant differential settlement, linear low density polyethylene (LLDPE) geomembranes are recommended due to their excellent elongation and flexibility characteristics.

On steep side slopes, the very low friction characteristics of the smooth geomembrane with adjacent layers may cause slope instability. Therefore, textured geomembranes may be needed to increase the cap side slope stability.

- The minimum geomembrane thickness should be 60 mils (0.06 inch or 1.5 mm) for polyethylene geomembranes (LLDPE, HDPE).

- A textured geomembrane can be used on side slopes to increase cap side slope stability.

5. Drainage Layer: Over the past decade the EPA Region I experienced two cases that caused a need for significant repair to a Superfund landfill cap; one was caused by settlement of the weak subsoil and another by an inadequate drainage system within the cap. Similar occurrence of landfill cap partial failures (or slides) has been reported [7] [8] [9] , most have occurred during, or immediately after, severe storm events. Often the effects of severe storm events over a short period of time (e.g., within a few hours) and resulting seepage forces within the drainage layer were neglected.

Currently the EPA[5] recommends that the granular drainage layer for final covers have a minimum thickness of 1 foot (30 cm) and a minimum permeability of 0.01 cm/sec. The EPA also recommends use of the HELP model to estimate percolation into the drainage layer and saturated depth over the low-permeability barrier on the basis of a daily precipitation data. Recent studies (Soong and Koerner, 1997 [8], and Thiel and Stewart, 1993[10]) indicate that the HELP generated percolation values significantly underestimate the hourly interval percolation values (at least 20 times) from severe storm events. Thus the HELP model program, based on a daily precipitation data is not appropriate to evaluate the worst case scenario which may create seepage induced slope instability. GRI's report [8]

---

[7] Boschuk, J.J., 1991, Landfill Covers: An Engineering Perspective, Geotechnical Fabrics Report, Vol.9, No.2, March, pp. 23-34.

[8] Soong, T. and Koerner, R.M., 1997, The Design of Drainage Systems over Geosynthetically Lined Slopes, GRI Report #19, June.

[9] Richardson, G.N., 1997, Fundamental Mistakes in Slope Design, Geotechnical Fabric Report, Vol. 15, No.2, March, pp. 15-17.

[10] Thiel, R.S. and Stewart. M.G., 1993, Geosynthetic Landfill Cover Design Methodology and Construction Experience in the Pacific Northwest, Geosynthetic 93 Conference Proceedings, pp 1131-1144.

also concluded that "The federal and state minimum permeability values for drainage soils (often taken and used directly in design) of 0.01 cm/sec are too low by a factor of 10, and in some cases 100.".

To prevent the potential for slope failures related to seepage forces, the EPA Region I recommends that a granular drainage layer (e.g., gravel or sandy gravel rather than sand) for landfill cap systems have a minimum thickness of 1 foot (30 cm) and a minimum permeability of 0.1 cm/sec. Properly functioning geocomposite drainage products may be substituted for a gravel drainage layer if equivalent long-term performance can be shown. The geocomposite can provide required flow values, can easily be installed over the geomembrane, and may provide additional puncture protection of the underlying geomembrane. Proper drainage systems, considering other effects (e.g., slope angle and length, freeze-thaw cycles), should be designed to reduce the hydraulic head being developed over the geomembrane and increase slope stability.

Therefore, the primary function of the drainage layer is to remove excess rainwater, minimize infiltration through the low permeability layer and to enhance the stability of the cover soil on side slopes. The drainage layer can consist of either a geocomposite or 12 inches (30 cm) of granular materials such as gravel or sandy gravel. It must be designed to facilitate the area's maximum foreseeable rainfall.

- A minimum thickness of 12 inches (30 cm) and a minimum slope of 3 percent, after allowance for settling and subsidence, are required to provide sufficient drainage flow as determined by the site-specific precipitation rate from a severe storm event over a short period of time. A 6-hour duration storm[6] can be considered as a severe storm event.

- The permeability of drainage material should be no less than 1×10^{-1} cm/sec.

- A gravel drainage layer may necessitate installation of a sufficiently thick non-woven geotextile at the bottom of the layer to protect the geomembrane from being punctured. A granular or geosynthetic filter should be placed directly over the drainage layer to minimize the migration of fines from overlying topsoil into the drainage layer.

- A geocomposite drainage layer consisting of two non-woven geotextiles heat-bonded to a drain core should have an equivalent (or required) hydraulic transmissivity[11] no less than 3×10^{-4}

---

[11] The equivalent (or required) hydraulic transmissivity can be determined by dividing the allowable hydraulic transmissivity by the design safety factor of 2 to 3. The allowable hydraulic transmissivity can be also determined from the ultimate hydraulic transmissivity data provided by the geocomposite supplier for performance testing (ASTM D4716) of the geosynthetic drainage product (e.g., geocomposite) after applying reduction factors due to long-term creep deformation, clogging effects, etc. . . (Koerner, R.M., 1994, Designing with Geosynthetics, 3rd Edition, Prentice Hall Publication Co., Englewood Cliffs, NJ., pp412-416). If the end product is a heat-bonded

m^2/sec. The top geotextile provides filter and separation functions and the bottom geotextile provides protection to the underlying geomembrane.

- The geocomposite drainage layer including the low permeability layer (i.e., geomembrane and low-permeability soil) and the drainage outlet system should be located below the maximum frost depth penetration.

6. Protective Soil Layer: The purpose of the protective soil layer is to provide a soil that is capable of sustaining the vegetative cover through dry periods and protect the underlying drainage and low permeability layers from frost damage and excessive loads.

7. Topsoil Layer: Below the vegetative cover is top soil which is required to support the vegetative cover. The topsoil layer will consist of a sand-silt-loam mixture to produce good vegetation.

- The final top slopes after allowance for settling and subsidence, should have a slope at least 3 percent to promote surface runoff during storm events while minimizing erosion. For the top areas of the landfill where slopes of 3 - 10 percent are common, the maximum horizontal spacing of diversions or ditches of 300 feet is recommended. A maximum erosion rate of 2.0 tons/acre/year as calculated with the USDA Universal Soil Loss Equation is required.

- Drainage benches (or terraces) should be used to breakup steeply graded slopes of covered landfill sites into less erodible segments. For slopes greater than 10 percent in steepness, the maximum distance between drainage benches should be equal to or less than 100 feet. Benches should also be of sufficient width and height to withstand a 24-hour, 25-year storm.

It is an important task of environmental geotechnics to establish principles in the design and construction of landfills, in particular with respect to long term safety. The new problems and materials involved in landfill design require new calculation methods to determine settlement, slope stability (both static and dynamic) of capping systems, proper drainage systems, etcetera. There are no satisfactory solutions to all problems which may arise in the day-to-day practice of landfill design and construction. The landfill design should be performed by a qualified geotechnical expert and must consider factors which are important to the construction, operation and closure of the landfill. This discussion is intended to highlight some of the problems and experiences of landfill design and construction to present solutions and approaches which may be beneficial to the designer, construction team, owner or operator of the

---

geocomposite, transmissivity data should be obtained for a heat-bonded geocomposite; and tested under a soil cover to reflect design drainage performance. The normal compressive load for design should also be at least 2 times higher than the field-anticipated normal pressure and hydraulic gradient be selected representative of the field condition (guideline for long term hydraulic performance of the geocomposite drainage layer in landfill cap applications is included in Appendix B).

landfill, and the environment.

II. EVALUATION OF ALTERNATIVE CAPS

The percolation of water through an EPA-recommended cap[5] for hazardous waste landfills and a proposed alternative cap, shown in Figure 1, was evaluated with the EPA Hydrologic Evaluation of Landfill Performance (HELP) computer model, Version 3.06 (August 1996). Although the HELP model may not estimate the hourly peak amount which would cause slope instability over geosynthetically lined slopes, the program may be used to estimate the annual average percolation through the cap components for comparison of designs.

The cap cross sections used for evaluation are as follows:

1. EPA-Recommended Cap[5]: Bottom 1 x 10^{-7} cm/sec permeability material (2 feet thick)/upper geomembrane (20 mils thick)/1 x 10^{-2} cm/sec permeability sand (1 foot thick) drainage layer.

2. Alternative Cap: Bottom 1 x 10^{-4} cm/sec permeability material (1 foot thick)/upper geomembrane layer (60 mils thick)/10 cm/sec permeability geocomposite drainage layer.

Default climatological data for Boston, Massachusetts were used to model the site climate (e.g., annual average precipitation = 43.08 inches). The cap slope length of 100 feet and side slope of 3 % were also assumed.

The HELP model results on cap performance for various cap sections are summarized in Table 1.

Table. 1 - Summary of Average Annual Percolation and Cap Efficiency Predicted by the HELP Model for Various Cap Sections

Cap Section	Annual Percolation (Inches)	Cap Efficiency* (%)
EPA-recommended Cap	0.00101	99.9976
Alternative Cap	0.00017	99.9996
Single Geomembrane Cap**	0.46407	98.9227

* Cap efficiency is defined as the sum of the percentage of percolation lost to runoff, evapotranspiration, and lateral drainage, and changes in the water storage system.

** Single geomembrane cap without a bottom low-permeability soil layer [i.e., geomembrane layer (60 mils thick)/10 cm/sec permeability geocomposite drainage layer] for comparison.

This evaluation indicates that the proposed alternative cap allows slightly less average annual percolation (or leakage) through the low-permeability layer than the EPA-recommended cap section[5]. Even the single geomembrane has a cap efficiency higher than 98.9%. This is primarily due to the fact that the relatively impermeable geomembrane (with a permeability of about 4×10^{-13} cm/sec) plays a primary role in limiting infiltration through the composite cap system. In addition, the use of a high-permeability geocomposite (about 10 cm/sec) instead of the sand drainage materials (with a permeability of 0.01 cm/sec) enhances the removal of water which infiltrates through the cover soil layer to an exit drain, so that the potential for infiltration through a geomembrane can be effectively minimized. Because the geocomposite drainage layer offers this and other benefits, including easier and faster construction, the geocomposite drainage layer is proposed for use in the cap.

In summary, the proposed alternative cap provides equal or better performance in minimizing annual percolation and any resulting leachate generation from the landfill into ground water compared with a cap system based on the EPA-recommended cap design guidance[5] for hazardous waste landfills.

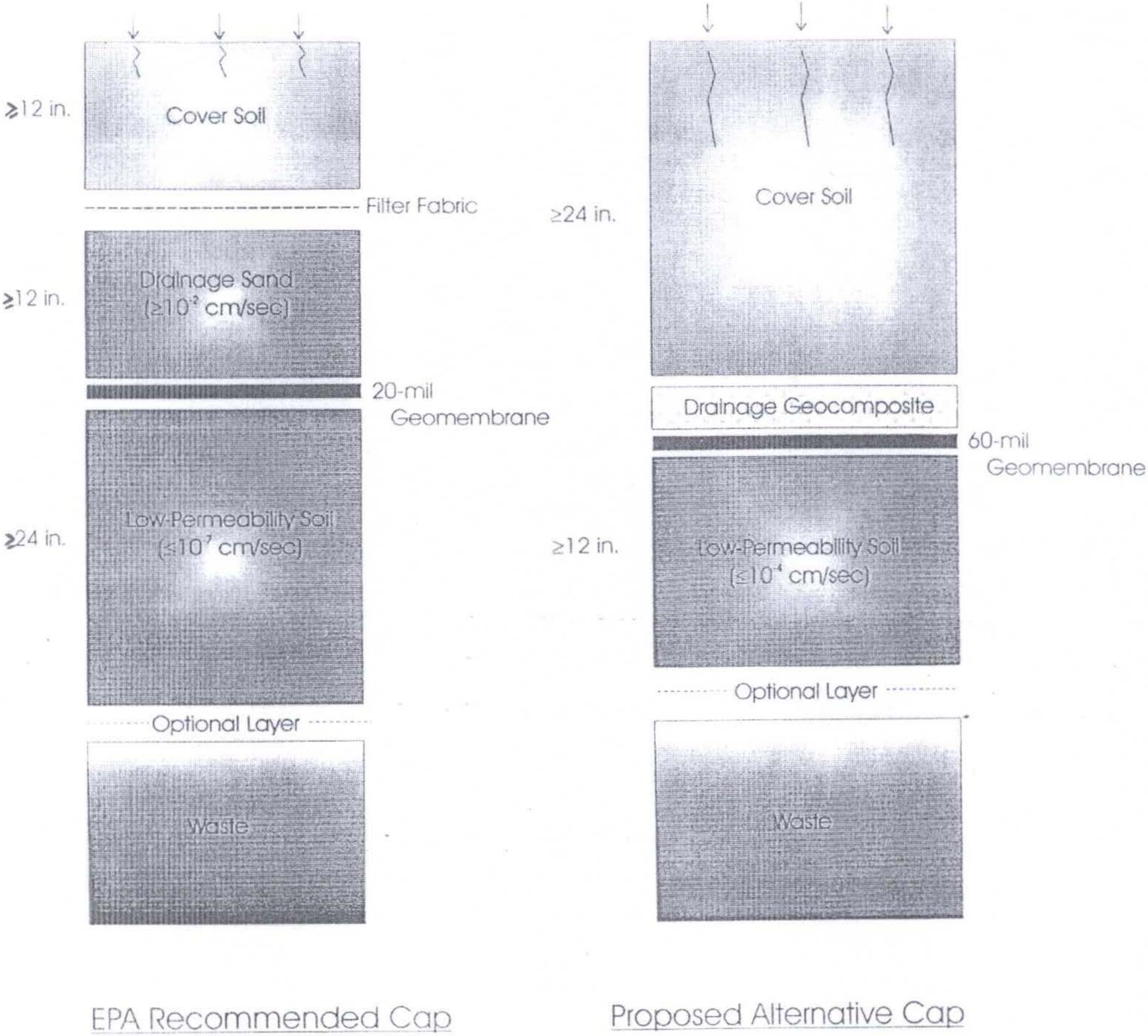

FIG. 1 LANDFILL CAP DESIGN

APPENDIX A

To: OSRR
From: Dennis P. Gagne, Chief
Technical Support and Site Assessment
Yoon-Jean Choi, P.E., Geotechnical Engineer
Technical Support and Site Assessment
Sharon Hayes, Remedial Project Manager
MA Superfund
Subject: EPA Region I Guidance and Performance Criteria for Polyethylene Geomembrane Welding used in Landfill Applications
Date: January 31, 2001

Polyethylene geomembranes {high density (HDPE), low density (LDPE)} are thin sheets of flexible, relatively impermeable, polymeric materials used as a primary hydraulic barrier in landfill applications (capping systems or bottom liner systems). They may be installed with minimal holes or damage. However, if poorly installed, these materials may hide defects or weaknesses that can lead to post-installation holes in and leakage of the geomembrane. Defects in the welds or repairs may be a potential long-term source of holes and damage of the geomembrane liners. This appendix provides a guidance and performance criteria for polyethylene geomembrane welding used in landfill applications. For an overview and additional details of current geomembrane seaming methods, refer to the EPA Technical Guidance Document: Inspection Techniques for the Fabrication of Geomembrane Field Seams (EPA/530/SW-91/051), EPA Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Facilities (EPA/600/R-93/182, September 1993) and DVS (Deutscher Verband für Schweissen) Direction 2225-1 (1991) and 2 (1992): Joining of Lining Membranes Made of Polymer Materials in Geotechnical and Hydraulic Engineering-Welding and Site Testing.

In all welding procedures, the joint surfaces have to be brought to the welding temperature required for the specific material used. Only the surface to which the welding force will be applied should be heated to keep the heat expansion of lining membranes as low as possible in the welded areas. Welding parameters such as temperature and pressure should be set so that the heat and mechanical stresses on the material are as low as possible and maximum long-term weld performance is obtained.

The ambient conditions at the time the weld is made have a considerable influence on the weld operation and thus on the quality of the bond. For this reason:

Welding should not be carried out in the rain unless protection has been arranged, and

Welding should be carried out only at ambient temperatures between 41EF and 104EF (5E-40EC). In case of extremely hot weather, geomembrane liner installation is recommended early in the morning or late in the afternoon {or under special provisions (e.g., tent)}.

Before the geomembrane installation begins at the site, test welds (or trial seams) should be carried out to adjust the welding process parameters to the field conditions and to verify that the welding machine is functioning properly.

Seam (or weld) quality is significantly influenced by welding speed, welding temperature, welding pressure, and site conditions. These parameters significantly affect the long term behavior of the adjacent geomembrane. Thus, controlling weld process parameters is critical to achieving consistent wedge welds over the possible range of field conditions.

Welding machines using the hot wedge welding method should be continuously monitored. When possible, record all welding process parameters (e.g., welding speed, welding temperature, wedge temperature, ambient temperature of the geomembrane surface, etc.) during the welding process to ensure that welding conditions were kept constant (for quality control and quality assurance).

The long-term behavior of a weld (strength, water tightness) can be influenced by the reduction of thickness in the weld area (i.e., seam thickness reduction). The seam thickness reduction is defined as the difference between the thickness of the two geomembranes and the welded seam thickness (measured by an ultrasonic device or other measuring devices). The seam thickness reduction reflects an actual interaction of welding parameters under changing field conditions (temperature, moisture, wind, etcetera) during the welding process. The weld thickness uniformity is an indicator of how uniform the welding process was maintained and the uniformity of the seam itself. Past field ultrasonic thickness measurement (e.g., Nyanza Chemical Superfund site, 2000) proved to be very effective in optimizing the welding of the geomembrane liner.

Ultrasonic thickness measurements should be performed at least every 25 feet on field seams joined using the hot wedge welding technique. This spacing should be reduced further if the seam thickness reductions are indicated beyond the allowable range.

According to DVS 2225, the allowable seam thickness reduction range must be within 8 - 32 mil (0.2 - 0.8 mm) for 100 mil (2.5 mm) thick HDPE geomembrane. However, based on our field experience, we recommend the following:

The seam thickness reductions for 60 - 80 mil (1.5 - 2.0 mm) HDPE and 60 mil (1.5 mm) LDPE geomembranes should be within 8 - 28 mil (0.2 - 0.7 mm) and 8 - 24 mil (0.2 - 0.6 mm), respectively. These are estimated values since long term seam reduction tests have been made only with HDPE geomembranes of 100 mil (2.5 mm) thickness (Bielefeldt, K. et al., Assessment of Long-term Performance of Weld Seams of Geomembranes for Landfill

Basal Liners and Cappings, Research Report SKZ FV 187, Würzburg, 1991).

The actual field seams (or production seams) should be carried out only after successful tests (or trial) of seams under field conditions. The ultrasonic thickness measurements on trial seams can provide optimum welding parameters for production seams. **We recommend that destructive testing of seams {peel test only(ASTM D 4437); no shear test} should be performed on geomembrane samples cut mostly from test seams instead of from field seams.** Destructive testing may be necessary to verify the strength of a weld but it requires samples to be cut from welded areas, which then should be repaired with a patch and extrusion welds. However, this process can lead to a weakness in the geomembrane liner. We suggest that actual field seam samples may be cut for destructive peel tests only at the start and end of the field seam if necessary.

- **#** Once the recorded welding parameters are constant and within the allowable tolerance range, a piece of the field seam should be cut out at the beginning and end of the seam, and a peel test should be performed with field testing instruments (i.e., tensiometer). The recommended test speeds for the HDPE and LDPE geomembranes are 2 in/min and 1 in/min, respectively (the graph of load versus displacement needs to be recorded). The seam is acceptable only if the basic material is stretched outside of the seam area without any peeling of the seam. The dimensions of the test pieces and evaluation of test results are provided in the standards of ASTM D 4437 or DVS-2226.

- **#** If the first test with the tensiometer is successful, the whole seam length should be tested by Air Channel Pressure Testing in accordance with ASTM D 5820.

- **#** For extrusion welding, three pieces of a trial seam should be cut out and the seam quality should be checked by means of a peel test. The effective welding should be tested using the Vacuum Box Method.

APPENDIX B

To: OSRR

From: Dennis P. Gagne, Chief
Technical Support and Site Assessment
Yoon-Jean Choi, P.E., Geotechnical Engineer
Technical Support and Site Assessment

Subject: EPA Region I Guideline for Long Term Hydraulic Performance Criteria of the Geocomposite Drainage Layer in Landfill Cap Applications

Date: March 23, 1999

As stated in the Alternative Cap Design Guidance [Gagne and Choi, 1997], the EPA Region 1 recommends that a geocomposite drainage layer (GDL) consisting of two non-woven geotextiles heat-bonded to a drain core should have an **equivalent (or required) hydraulic transmissivity ($T_{required}$) no less than 3×10^{-4} m^2/sec** as an alternative for a gravel drainage layer.

Since landfill caps are typically designed to sustain more than 30 years, one must ensure that the GDL products have the capability of maintaining proper hydraulic transmissivity over the intended design life of the structure. EPA Region 1 currently recommends design of the GDL using short-term transmissivity (or flow rate) laboratory test results which simulate site-specific field conditions. The short-term hydraulic transmissivity values (**T_{lab}**) should be determined in accordance with ASTM D4716 with the following conditions:

- Testing configurations include steel plate/site-specific soil/GDL/geomembrane/steel plate.

- Applied normal stress is 1000 psf or 2 times the field-anticipated maximum value, whichever is greater

- Hydraulic gradients should be 0.10, 0.20, 0.35 and 0.50.

- Seating period should be at least 100 hours or until equilibrium is reached, whichever is greater.

The minimum hydraulic transmissivity (T_{lab} obtained from ASTM D4716 test) selected for the geocomposite drainage layer should be at least 2.4×10^{-3} m^2/sec after considering the product of all proper long-term reduction factors (about 4.0) due to creep, geotextile intrusion, chemical degradation of polymeric compound, physical clogging, biological clogging, chemical clogging, scaling effects..., and a design factor of safety (2.0):

#	$T_{required} = T_{lab}$/[(product of all partial long-term reduction factors) x (design safety factor)], or

#	$T_{lab} = T_{required}$ x (product of all partial long-term reduction factors) x (design safety factor)

$= (3 \times 10^{-4}\ m^2/sec) \times 4.0 \times 2.0$

$= 2.4 \times 10^{-3}\ m^2/sec$