MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION

BUREAU OF WASTE SITE CLEANUP

GUIDANCE ON THE USE, DESIGN, CONSTRUCTION, AND MONITORING OF ENGINEERED BARRIERS

Public Comment Draft

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1.0 BACKGROUND

Under revisions incorporated into the Massachusetts Contingency Plan (MCP) in 1997, a Class A-4 Response Action Outcome can be filed for a site where the average soil concentration of oil and/or hazardous material exceeds an applicable Upper Concentration Limit, if such soil is overlain by an *engineered barrier*. Pursuant to the provisions of 40.0996(4)(c), an engineered barrier:

1. shall prevent direct contact with contaminated materials;
2. shall control any vapors or dust emanating from contaminated media;
3. shall prevent erosion and any infiltration of precipitation or run-off that could jeopardize the integrity of the barrier or result in the potential mobilization and migration of contaminants;
4. shall be comprised of materials that are resistant to degradation;
5. shall be consistent with the technical standards of RCRA Subpart N, 40 CFR 264.300, 310 CMR 30.600 or equivalent standards;
6. shall include a defining layer that visually identifies the beginning of the barrier;
7. shall be appropriately monitored and maintained to ensure the long-term integrity and performance of the barrier. Plans for the monitoring and maintenance of the barrier shall be submitted to the Department and shall document that one or more financial assurance mechanism(s) have been established and adequately provide for future monitoring, maintenance and any necessary replacement of the barrier; and
8. shall not include an existing building, structure or cover material unless it is designed and constructed to serve as an engineered barrier pursuant to the requirements of 310 CMR 40.0996(4).

In articulating the use of a RCRA (i.e., federal Resource Conservation and Recovery Act) technical standard, the MCP at 40.0996(4)(c)(5.) sets a “high bar” for the design, construction, and monitoring of engineered barriers. However, because state and federal RCRA regulations and guidance documents are predicated on the assumption of a site-by-site regulatory approval mechanism, they lack definitive technical standards and specificity. This limitation has lead to a considerable range of opinions and positions within the regulated community in Massachusetts on what constitutes an acceptable engineered barrier.

2.0 PURPOSE, SCOPE, AND APPLICABILITY

The purpose of this document is to provide clarification and guidance on achieving compliance with the regulatory requirements of 40.0996(4), to help ensure protective and consistent applications of this remedial action alternative.

In this guidance document DEP:

- provides a summary of existing regulatory *requirements and provisions* on the use, design, construction, and monitoring of engineered barriers;
- articulates the broad *performance standards* contained in the MCP for the use, design, construction, and monitoring of engineered barriers; and
- provides and discusses a detailed set of *recommended specifications* deemed compliant with relevant performance standards and regulatory requirements.

It is important to understand that the recommendations contained in this policy are not regulatory mandates. However, parties choosing to use these specifications will have certainty on the acceptability of their design, construction, and monitoring proposals and efforts. Alternatively, parties may elect to pursue a more site-specific approach, with appropriate supporting rationale and documentation to demonstrate compliance with regulatory and technical performance standards.

3.0 DISCLAIMER

The information contained in this document is intended solely as guidance. This document does not create any substantive or procedural rights, and is not enforceable by any party in any administrative proceeding with the Commonwealth. In addition to summarizing specific requirements, this document also provides guidance on what measures DEP considers acceptable for meeting the general requirements set forth in the regulations. Parties using this guidance should be aware that there may be acceptable alternatives to this guidance for achieving compliance with regulatory requirements.

4.0 REGULATORY REQUIREMENTS AND PERFORMANCE STANDARDS

Based on relevant provisions of 310 CMR 40.0000, and an interpretation and application of the regulatory provisions and discretionary authority provided in RCRA Subpart N, 40 CFR 264.300 and 310 CMR 30.0600, the Department's position on when and how an engineered barrier may be constructed can be summarized in the following two statements:

- **The use of an engineered barrier shall be limited to disposal sites where there are no other feasible alternative(s) to**
    - **reduce concentrations of oil and/or hazardous material in soil to levels below Upper Concentration Limits; and/or**
    - **fixate contaminants present in soil in a manner that will reduce or eliminate environmental mobility and physiological availability.**
- **The design, construction, and post-construction monitoring of engineered barriers must be consistent with (1) the technical standards and industry practices for hazardous waste ("RCRA") landfills; (2) the toxicity and/or mobility of contaminants of concern; and (3) the sensitivity and use of the disposal site and adjacent properties.**

Further elaboration, explanation, and justification of this position are provided below.

4.1 USE OF AN ENGINEERED BARRIER

Because it is not possible to detail or even anticipate every response action concern or need in a privatized waste site cleanup program, the MCP articulates an overall Response Action Performance Standard (RAPS) at 40.0191.

Under the provisions of 40.0191(3), the evaluation and selection of a remedial action alternative for a disposal site must consider the following:

- *technologies which reuse, recycle, destroy, detoxify or treat oil and/or hazardous materials, where feasible, to minimize the need for long-term management of contamination at or from a disposal site;*

- *containment measures as feasible Permanent Solutions only where reuse, recycling, destruction, detoxification, and treatment are not feasible;*

- *remedial actions to reduce the overall mass and volume of oil and/or hazardous material at a disposal site to the extent feasible, regardless of whether it is feasible to achieve one or more Temporary Solutions and/or Permanent Solutions or whether it is feasible to achieve background for the entire disposal site.*

In addition to RAPS provisions of 40.0191, requirements and allowances for the use of an engineered barrier are specifically provided in several sections of the MCP, including 40.0859(4), 40.1036(4)(e), and 40.1056(2)(f). The issue is most directly addressed in the "Feasibility" provisions of 310 CMR 40.0860:

- Under the provisions of 40.0860(5), an engineered barrier may not be selected as a remedial option at a disposal site if a feasible alternative exists that will reduce concentrations of oil and hazardous material in soil to levels at or below applicable Upper Concentration Limits. Feasibility in this context is primarily related to the evaluation of the benefits and costs of alternative measures, as further outlined in 40.0860(7).

- For the Benefit-Cost Analysis detailed in 40.0860(7), the feasibility of reducing concentrations of oil and hazardous materials is primarily a function of the criterion articulated in paragraph (a), which specifies that alternatives to the use of engineered barriers shall be considered feasible unless "*the incremental cost of conducting the remedial action alternative is substantial and disproportionate to the incremental benefit of risk reduction, environmental restoration, and monetary and non-pecuniary values*".

  The costs associated with alternative remedial options are generally ascertainable with a reasonable degree of certainty. The benefits of such alternatives are more difficult to quantify. When considering alternatives to the use of an engineered barrier, however, it is the agency's position that, at a minimum, the following benefits must be considered:

  - The monetary benefits in eliminating or reducing the long-term (perhaps perpetual) costs associated with monitoring, maintaining, repairing, and/or replacing the engineered barrier; and

  - The public health, safety, and/or environmental benefits of eliminating the long-term (perhaps perpetual) existence of a potential exposure pathway to high concentrations of oil and/or hazardous material.

Finally, in accordance with the provisions of 40.0996(6), it should be noted that an engineered barrier is not sufficient to achieve a permanent solution at a site where concentrations of oil or hazardous material are present in groundwater at concentrations greater than an Upper Concentration Limit, or at sites where Non-Aqueous Phase Liquids are present at a thickness greater than 1/2 inch.

4.2 TECHNICAL STANDARDS

Technical standards for engineered barriers are explicitly cited at 40.0996(4)(c)(5.) by reference to RCRA Subpart N, 40 CFR 264.300, and 310 CMR 30.600.

To assist governmental project managers in making decisions on such containment technologies, the USEPA has published a number of detailed guidance documents on such “RCRA” and “CERCLA” caps. In addition to providing valuable technical assistance and direction, the recommendations contained in these publications are directly applicable to activities regulated by the MCP, given the RAPS provisions of 40.0191(2), which require, in part, “consideration of relevant policies and guidelines issued by the Department and EPA.”.

Among the more relevant and useful publications in this regard are the following, which form the basis of most of the requirements and recommendations contained in this guidance document:

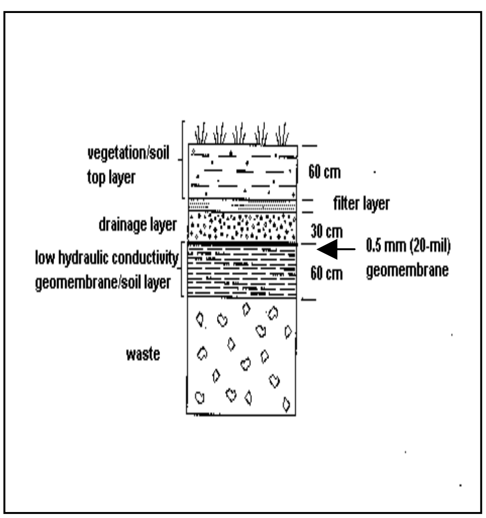
- USEPA, *Design and Construction of RCRA/CERCLA Final Covers*, EPA/625/4-91/025, May 1991.

- USEPA, *Evaluation of Subsurface Engineered Barriers at Waste Sites*, EPA 542-R-98-005, August 1998.

- *Revised Alternative Cap Design Guidance Proposed for Unlined, Hazardous Waste Landfills in the EPA Region I*, USEPA, Region I, February 5, 2001.

Additional publications relevant to this issue, and/or publications used in the drafting of this guidance document are listed in Section 7.0.

4.2.1 In *Design and Construction of RCRA/CERCLA Final Covers (*EPA/625/4-91/025), the USEPA provides detailed technical information and guidelines on “RCRA” caps. Figures 1-1 and 1-2 from this publication (reproduced below) represent EPA’s recommended landfill cover design for the final cover of waste/ contaminated materials at RCRA and CERCLA sites.



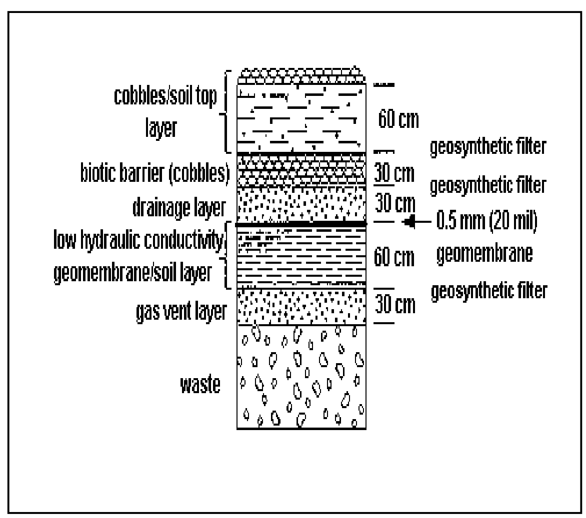


Figure 1-1.USEPA-recommended landfill cover design Figure 1-2. USEPA-recommended landfill cover with options

4.2.2 In *Evaluation of Subsurface Engineered Barriers at Waste Sites*, the USEPA provides additional and more current technical guidance and observations on caps and subsurface barriers. Of particular interest in this document are information and conclusions on current industry standards for Quality Assurance/Quality Control practices in the design, construction, and inspection of engineered barriers.

4.2.3 While EPA/625/4-91/025 and EPA 542-R-98-005 provide general guidelines, specifications, and observations for sites throughout the United States, *Revised Alternative Cap Design Guidance Proposed for Unlined, Hazardous Waste Landfills in the EPA Region I* provides specific guidance for capping efforts in New England. Moreover, the recommendations contained in this publication incorporate recent advances in technology and materials, and recent experiences and observations on successful (and unsuccessful) capping projects within and outside of the region.

4.3 QUALITY ASSURANCE/QUALITY CONTROL

In accordance with the RAPS provisions of 40.0191(2), it is DEP's position that the design and construction of engineered barriers should be conducted in accordance with the "Acceptable" industry practice for caps at "RCRA" landfills, as presented in the USEPA publication *Evaluation of Subsurface Engineered Barriers at Waste Sites*, EPA 542-R-98-005, August 1998. A summary of these provisions is provided in the Appendix.

All relevant information, data, and modeling related to the above activities must be included in the Remedial Action Plan and/or Remedy Implementation Plan submitted for the disposal site.

4.4 POST-CONSTRUCTION USE

The MCP at 310 CMR 40.0996(4)(c)(7.) and 40.1012 requires that (i) appropriate steps be taken to maintain barrier functionality, and (ii) limit and control site uses to ensure long-term protection of human health, safety, public welfare, and the environment, respectively. In order to adequately comply with these mandates, at a minimum, the following are necessary post-construction use considerations and conditions at sites where an engineered barrier is the selected remedial action alternative:

- Activities and uses inconsistent with or deleterious to the operation of the engineered barrier shall not be permitted at the site. Such activities may include, but are not limited to, the following:

    - any activity that would promote erosion or excessive/differential settlement of the engineered barrier;

    - any planting of vegetation within or above the engineered barrier that would compromise the integrity of the soil layers via root infiltration;

    - any construction or use of subsurface wastewater disposal systems or underground injection wells within, below, above, or adjacent to the engineered barrier; or

- any other use that would adversely affect the integrity or functionality of the engineered barrier.

- All excavations into or below the engineered barrier must be expressly prohibited, unless reviewed and approved by a Licensed Site Professional, and unless and until notice is provided to DEP, as specified in 40.1080.

- All prohibited and regulated activities at the site, and all requirements for the post-construction inspection, monitoring, maintenance, and repair of the engineered barrier, must be referenced or incorporated into the Activity and Use Limitation filed for the site.

4.5 POST-CONSTRUCTION MONITORING AND MAINTENANCE

The MCP at 310 CMR 40.0996(4)(c)(7.) requires post-construction monitoring and maintenance of engineered barriers. Based on an interpretation and application of relevant and analogous regulatory provisions in this regard, the following procedures and requirements shall apply:

- Consistent with the provisions of 310 CMR 30.633 and 310 30.592B(3), post-construction monitoring must occur for a minimum of 30 years following the construction of the engineered barrier, or until an engineered barrier is no longer required at the site to maintain a condition of No Significant Risk. DEP may extend this post-construction monitoring period at any time prior to the expiration of this 30-year timeframe if the agency determines that such an action is necessary to protect public health, safety, welfare, or the environment.

- In accordance with the provisions of 40.0996(4)(c)(7.), post-construction activities must be memorialized in a written plan submitted to DEP following construction of the engineered barrier, at or prior to the submittal of the Class A-4 RAO. At a minimum, this plan should detail the following:

    - *The name, address, and telephone number(s)* of the person(s) responsible for implementation of the post-construction activities plan, together with the name, address, and telephone number of the Licensed Site Professional who will oversee implementation of the post-construction monitoring and maintenance plan.

    - *Plans and provisions for the periodic inspection of the engineered barrier, to observe the integrity of cover and barrier systems, maintain appropriate signage, and document changes in site activities or uses that may negatively impact the integrity or function of the engineered barrier*. Inspections of engineered barriers containing a vegetative cover should occur at least every 3 months for the first year following construction, and at least yearly thereafter; additional inspections of soil covers should occur following severe storms (i.e., storms with an average 10 year or greater return period). All other engineered barriers should be inspected on at least a yearly basis. Inspections conducted on a yearly basis should be undertaken during the months of April or May. Within 30 days following such an inspection, but no later than June 1st, a written report should be submitted to the appropriate regional office of DEP memorializing the results of this inspection, and detailing any deficiencies or needed corrective actions.

- *Plans and provisions for the periodic sampling of groundwater and/or soil gas monitoring wells*, if contaminants immobilized by the engineered barrier are considered soluble and/or volatile, as discussed in this guidance document.

- *Plans and provisions for the periodic maintenance of the engineered barrier*. Such plans should specify, to the extent necessary and appropriate, continuing requirements for erosion and/or subsidence control measures, pavement maintenance, and/or landscaping measures.

- *Contingency plans and provisions to be implemented in the event of an unanticipated failure of the engineered barrier*. Such plans should specify, to the extent necessary and appropriate, procedures and specifications for the replacement of the Separation Layer, geomembranes, Low Permeability Barrier, and/or gas venting layers.

4.6 DOCUMENT PREPARATION AND SUBMITTAL REQUIREMENTS

The design, construction, and monitoring of engineered barriers must comply with all applicable document preparation and submittal requirements of the Massachusetts Contingency Plan (MCP), as well as all other applicable federal, state, and local laws, regulations, and ordinances. A list of important provisions in this regard includes, but is not limited to, the following:

- In accordance with the provisions of 310 CMR 40.0191 (1) and (3), 40.0859(4), 40.0860 (3) and (4), 40.1036(4)(e), and 40.1056(2)(f), an engineered barrier will not be considered an acceptable Permanent Solution at a disposal site unless and until a detailed Phase III evaluation is conducted in conformance with 40.0858. This evaluation must demonstrate the lack of a feasible alternative to reduce concentrations of oil and/or hazardous materials in soils to levels below Upper Concentration Limits and to levels that approach or achieve background, and/or fixate contaminants present in soil in a manner that will reduce or eliminate environmental mobility and physiological availability.

- In accordance with the provisions of 40.0414 and 40.0442, an engineered barrier constructed as part of an Immediate Response Action (IRA) or a Release Abatement Measure (RAM) will not be considered part of a Permanent Solution at a disposal site unless and until a detailed Phase III evaluation is conducted in conformance with 40.0858 which demonstrates the lack of a feasible alternative. In addition, such an evaluation is necessary to ensure compliance with the provisions of 40.0411(4) and 40.0442(1), which place limitations on the scope and complexity of IRAs and RAMs, and specifically state that an IRA or RAM shall not:

    - be implemented without a level of understanding of disposal site conditions and surrounding receptors sufficient to support the actions taken; or

    - prevent or impede the implementation of likely future response.

- In accordance with the provisions of MGL c. 112, §81D and 250 CMR 4.00 and 5.00, certain assessment and/or design activities associated with the construction of an engineered barrier will require the services and stamp of a registered professional engineer. Of particular relevance are geotechnical and structural consultations, investigations, evaluations, plans, designs, and supervision of construction for the purpose of assuring compliance with the specifications and design.

- In accordance with the provisions of 40.0875(1)(b), As-Built Construction plans shall be prepared and submitted to DEP for any disposal site where an engineered barrier is constructed.

- In accordance with the provisions of 40.1036(4)(c), one or more Activity and Use Limitations shall be implemented pursuant to 40.1012 at all sites where an engineered barrier is constructed and a Class A-4 Response Action Outcome is achieved.

5.0 FINANCIAL ASSURANCE MECHANISMS

As specified in 310 CMR 40.0996(4)(c)(7.), one or more financial assurance mechanisms must be provided for disposal sites where an engineered barrier is constructed, in order to (a) ensure completion of the items specified in the post-construction activities plan, and (b), where necessary and appropriate, ensure funding for the complete replacement of barrier systems destroyed during a significant and/or sudden failure event. Such mechanisms shall be completed and fully functional at or prior to the submittal of the Class A-4 RAO, which must include all relevant financial assurance documentation.

5.1 ROUTINE POST-CONSTRUCTION MONITORING AND MAINTENANCE (ALL SITES)

Sufficient funds must be available for all sites to ensure implementation of post-construction monitoring and maintenance activities, as specified in the post-construction activities plan.

The amount of funds secured for this purpose should be as determined by the LSP of record based upon a site-specific, present-worth analysis of funding needs to implement the post-construction activities plan. In general, at a minimum, this estimate should provide for:

- at least $30,000 (total) as a one-time allocation for a yearly inspection and monitoring program; AND

- at least $50,000 per acre (or portion thereof) as a one-time allocation, to be available for scheduled or needed maintenance or repair activities; AND

- at least $20,000 as a one-time allocation for a groundwater/soil gas monitoring program, if needed.

5.2 SUDDEN AND/OR SIGNIFICANT FAILURE OF ENGINEERED BARRIER (SOME SITES)

Certain sites and installations are more prone to a sudden and significant failure of key barrier elements. Such concerns are almost always related to seepage-induced instability of side slopes during a severe storm event. Accordingly, a separate, short-term funding mechanism should be provided to cover the complete cost of replacement of all portions of an engineered barrier with a top or side slope equal to or greater than 3 (horizontal) to 1 (vertical).

The amount of funds secured for this purpose should be as determined by the LSP of record based on a site-specific analysis of funding needs to cover the complete cost of replacement of relevant areas of the engineered barrier, inclusive of all design and construction activities. Such a funding mechanism must remain accessible and viable for at least 5 years following the submittal of the Class A-4 RAO for the disposal site.

5.3 FINANCIAL ASSURANCE INSTRUMENT

The financial assurance mechanism(s) required in Sections 5.1 and 5.2 should consist of one or more of the following instruments, as further detailed in 310 CMR 30.906:

- Post-Construction Trust Fund;
- Surety Bond guaranteeing payment into a Post-Construction Trust Fund;
- Surety Bond guaranteeing performance of post-construction care;
- Post-Construction Letter of Credit; and/or
- Post-Construction Insurance.

Alternative financial assurance mechanisms may be considered for governmental facilities and/or other public or private entities where use of one of the above vehicles is unnecessary or impractical.

6.0 RECOMMENDED DESIGN AND CONSTRUCTION SPECIFICATIONS

6.1 DESIGN OBJECTIVES AND APPROACH

An engineered barrier has two design objectives:

- *isolate* contaminants from human activity; and
- *contain* volatile and/or soluble contaminants.

6.1.1 Isolation

In all cases, an engineered barrier must be designed and constructed in a manner that ensures an adequate degree of long-term isolation of site contaminants from unplanned and/or unregulated human interaction. The degree of necessary isolation is a function of contaminant toxicity, persistence, and human exposure potential. The design of such barriers must consider current and foreseeable land uses and must adequately address long-term physical forces relating to differential settlement, thermal expansion, freeze/thaw cycles, erosion, and abrasion.

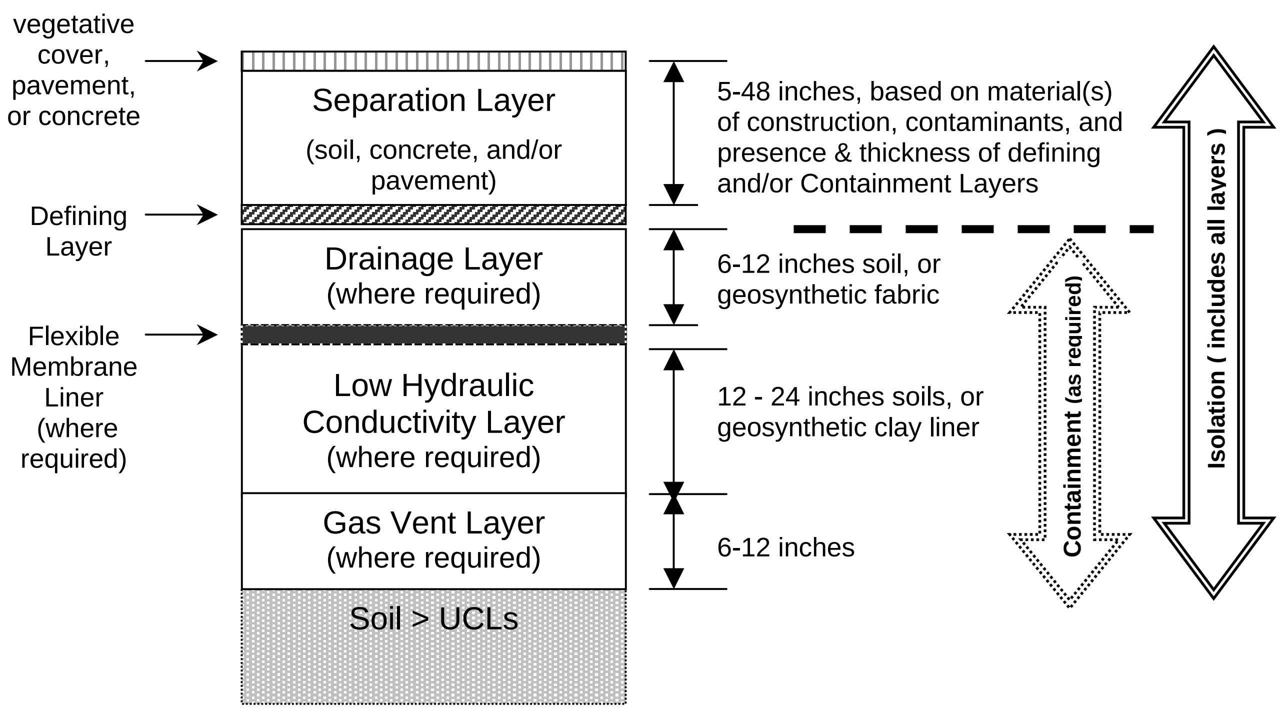
6.1.2 Containment

Unless adequate justification is presented on the lack of contaminant mobility, an engineered barrier should also include a low-permeability barrier and gas collection system.

6.2 DESIGN SPECIFICATIONS

All possible components of an engineered barrier are illustrated in Figure 2.

Figure 2 – Engineered Barrier Design Components



6.2.1 **Separation Layer** – The purpose of the Separation Layer is to isolate contaminants from potential human interaction, in order to minimize the future, long-term possibility of inappropriate disturbance/excavation of underlying soils, including unintended and/or unauthorized activities by (unprotected) construction crews. At most sites, the Separation Layer should be constructed out of clean soil, bituminous pavement, reinforced concrete, and/or some combination thereof. At sites where additional barrier elements are present (i.e., Containment Layers), the Separation Layer is one component in the overall isolation of underlying contaminants. At sites where additional barrier elements are not necessary, the Separation Layer must provide all needed isolation and/or encapsulation of underlying contaminants.

A soil Separation Layer should be overlain by a vegetative or armored top surface (e.g., pavement, concrete). Vegetative top surfaces should be graded at a slope between 3% and 5%; side slopes should not exceed 1:3. Additional details on options and expectations for the Separation Layer are discussed in Section 6.3.

6.2.2 **Defining Layer** – The Defining Layer should be comprised of a geofabric, horizontal plastic snow fencing, horizontal chain-link fencing, grids of Warning Tape, or another inert material or unit that visually demarcates and identifies the area of concern. The defining layer should be situated below the Separation

Layer. If appropriate, a geosynthetic material used as a Drainage Layer may be considered a Defining Layer.

6.2.3 Containment Layer – Where required, the Containment Layer should be comprised of an integrated system of natural and/or synthetic materials acting in a coordinated manner to minimize the infiltration of surface water into underlying contaminated soils, and/or contain and control the migration of contaminant vapors and/or biogenic gases. The Containment Layer should contain the following elements, as dictated by site conditions and contaminant migration concerns:

6.2.3.1 *Gas Vent Layer* – should be comprised of a layer of compacted soil at least 6-12 inches in thickness with a minimum hydraulic conductivity of 1×10^{-2} cm/sec. The Gas Vent Layer and supporting piping and venting network should be constructed below the Low Permeability Barrier. Alternatives for the Gas Vent Layer are discussed and detailed in Section 6.4.

6.2.3.2 *Low Permeability Barrier* – should be comprised of a Low Hydraulic Conductivity Layer in intimate contact with a Flexible Membrane Liner (FML).

<u>Low Hydraulic Conductivity Layer</u>

At a minimum, this component of the engineered barrier should consist of the following:

- a 24 inch layer of compacted natural or amended soil with a maximum hydraulic conductivity of 1×10^{-7} cm/sec, in intimate contact with a minimum 0.5 mm (20-mil) FML; or

- a 12 inch layer of compacted or amended soil with a maximum hydraulic conductivity of 1×10^{-4} cm/sec, in intimate contact with a minimum 1.5 mm (60-mil) FML.

The last lift of the compacted soil layer (that will be in contact with the FML) should contain no stones larger than ½ inch, and should have a minimum slope of 3% after allowance for settlement.

In lieu of a compacted soil layer, the use of a Geosynthetic Clay Liner (GCL) may be an acceptable Low Hydraulic Conductivity Layer, provided that adequate product and site-specific evaluation is conducted of puncture resistance, wet/dry and freeze/thaw effects, long-term GCL/fiber stability, and other relevant factors. Because of the frictional characteristics of the interface between a GCL and FML, however, the use of such systems is not recommended for slopes greater than 6 (horizontal) to 1 (vertical).

Other alternatives for the Low Hydraulic Conductivity Layer are discussed and detailed in Section 6.4.

<u>Flexible Membrane Layer (FML)</u>

The FML component of the engineered barrier is a flexible, relatively impermeable polymeric geomembrane in intimate contact with a Low

Hydraulic Conductivity Layer. The recommended thickness of the FML is a function of the extent and permeability of the underlying Low Hydraulic Conductivity Layer, as detailed above. In general, thicker FML installations are preferred, because they are better able to resist chemical attack, temperature changes, puncturing, etc. At sites where significant post-construction differential settlement is possible, linear low-density polyethylene (LLDPE) geomembranes are recommended, due to their superior elongation and flexibility characteristics. On side slopes, the use of textured geomembranes should be considered to increase cap stability.

A critical element in the long-term performance of FMLs is quality control and quality assurance procedures employed during installation. Using "good" installation and QA/QC procedures, one hole/acre can be expected in the FML, with an area of 0.1 cm^2 (EPA/625/4-91/025). To achieve this level of quality, the following steps and procedures are recommended:

- Welding of FML seams should generally not occur at ambient temperatures less than 41° F or greater than 104 ° F, or during inclement weather.

- Ultrasonic thickness measurements should be performed at least every 25 feet on field seams joined using the hot wedge welding technique. 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.

- Destructive testing of seams (peel test via ASTM D 4437) should be performed on the installed FML, preferably from seams at the outer edges of the installation, followed by testing of the entire seam length by Air Channel Pressure Testing in accordance with ASTM D 5820.

6.2.3.3 *Drainage Layer* - should be comprised of a minimum 6-12 inch layer of soil with a minimum hydraulic conductivity of 1 x 10^{-2} cm/sec and minimum slope of 3%. In lieu of soil, the Drainage Layer may be comprised of a geocomposite product consisting of two non-woven geotextiles heat-bonded to a drain core possessing an equivalent hydraulic transmissivity no less than 3 x 10^{-4} m^2/sec (as detailed in Section 7.0, Reference 5). A predictive model (e.g., HELP) should be used to provide site-specific estimates of percolation into the Drainage Layer and build up of hydraulic head over the Low Permeability Barrier, to aid in the design and evaluation of the selected installation.

Although the primary function of the Drainage Layer is to help minimize the long-term infiltration of surface waters through the Low Permeability Barrier, this unit is also a critical element in the stability of side slopes. Seepage-induced instability has been the cause of a number of slope failures at capped sites in New England. For this reason, while estimates of daily rates are appropriate to predict long-term infiltration of water through a Low Permeability Barrier, **hourly interval percolation values for a severe storm event are recommended to evaluate the adequacy**

of a Drainage Layer design for slope stability purposes. Where appropriate, this evaluation should also include a consideration of the impacts of area run-on and drainage discharges onto the engineered barrier.

6.2.4 **Extent of Engineered Barrier** - The engineered barrier should extend in full thickness and with all design features a minimum of 4 feet beyond the horizontal boundaries of soils contaminated with oil or hazardous materials above an applicable Upper Concentration Limit, as permitted by site conditions (e.g., presence of wetlands, property boundaries, etc.) At sites where the engineered barrier must extend to a structure, an appropriate interface must be designed and constructed.

6.2.5 **Soils** - Soils used in the construction of an engineered barrier must be of suitable and adequate physical and chemical quality.

- Soils used as cover must be free of materials that may be deleterious to the short or long-term functionality of the engineered barrier.

- In order to minimize the potential occurrence of frost heaves and/or upward migration of waste materials and dissolved contaminants, soils used in the construction of an engineered barrier (exclusive of the Low Hydraulic Conductivity Layer and vegetative cover) should not contain more than 3% fines (by weight) smaller in size than 0.02 mm.

- Because of the deleterious effects of freezing, compacted clay soils, when used as a Low Hydraulic Conductivity Layer, should be constructed below the frost zone.

- Soils used in the construction of an engineered barrier within or above the Separation Layer must not contain concentrations of oil or hazardous material in excess of levels suitable for soils at the disposal site, as specified in 310 CMR 40.0900.

6.2.6 **Material Compatibility** – All materials used in the construction of an engineered barrier must be compatible with the contaminants and conditions at the site in question. Of particular concern is the effect of corrosive and/or acidic wastes or vapors on geofabrics, Flexible Membrane Liners, bituminous pavement, and reinforced concrete structures.

6.2.7 **Geotechnical Analysis -** An analysis of barrier stability, integrity, and durability should be conducted at sites where concerns exist over excessive and/or differential settlement, slope stability, erosion potential, and/or frost heaves. Such an analysis should typically be conducted by a qualified geotechnical engineer registered in the state of Massachusetts and should be documented in the Remedial Action Plan. Sufficient information and justification should be provided to demonstrate that site conditions and/or barrier design elements would not unacceptably impact long-term barrier functionality. Conditions of concern include, but are not limited to, the following:

- engineered barriers placed over highly organic soils and/or waste materials, where significant and/or differential settlement is possible due to physical and biochemical activities;

- engineered barriers incorporating geo-membranes and/or geocomposite Drainage Layers on slide slopes, due to concerns over interface stability and sudden slope failures; and/or

- engineered barriers that do not fully penetrate the frost zone.

6.3 RECOMMENDED OPTIONS FOR CONTAMINANT ISOLATION

The recommended design for the Separation Layer at most sites is (a) 12 to 48 inches of suitable soils, depending on the presence and thickness of other engineered barrier components, (b) 8 inches of bituminous pavement, or (c) 5 inches of reinforced concrete. Combinations of materials are also permissible. Notwithstanding the above recommendations, at certain sites where highly toxic contaminants are present, the Separation Layer should consist of a slab of reinforced concrete at least 8 inches in thickness. A summary of these recommendations is provided in Table 1.

Table 1 – Recommended Design of the Separation Layer

<table>
<tr><th>Soil Contaminant(s) in Excess of Upper Concentration Limit</th><th>Material of Construction</th><th>Minimum Thickness</th></tr>
<tr><td rowspan="3">Most Oil and Hazardous Materials
(3 options/combination
of options recommended)</td><td>Suitable Soils</td><td>48 inches, minus 1inch for every inch of (soil/geoeofabric/geomembrane) Containment Layer</td></tr>
<tr><td>Bituminous Pavement</td><td>8 inches, minus 1 inch for every 6 inches of Containment Layer and/or sub-base</td></tr>
<tr><td>Reinforced Concrete</td><td>5 inches, minus 1 inch for every 10 inches of Containment Layer and/or sub-base</td></tr>
<tr><td>Highly Toxic Hazardous Materials at a 1-4 Family Residence</td><td rowspan="2">Reinforced Concrete</td><td rowspan="2">8 inches (regardless of any other capping elements)</td></tr>
<tr><td>Chemicals with Severe/Lethal Health Effects at any Location</td></tr>
</table>

6.3.1 Use of Concrete or Bituminous Pavement as a Separation Layer

Except as noted in Section 6.3.2, an acceptable Separation Layer design would be a 5-inch slab of concrete or 8 inch layer of bituminous pavement, underlain by a suitable sub-base material. Where appropriate, a concrete Separation Layer may be part of a building structure that overlies the engineered barrier.

a) <u>Concrete</u> - A concrete Separation Layer should be a cast-in-place slab of steel-reinforced, air-entrained Portland-cement concrete a minimum of 5 inches in thickness. The concrete slab should have a minimum 28-day compressive strength of 4000 psi, designed and constructed in a manner consistent with the technical standards outlined in Section 476 of the

Massachusetts Highway Department's *Standard Specifications for Highways and Bridges*.

b) Bituminous Pavement – A bituminous pavement Separation Layer should be a full-depth hot-mix asphalt pavement structure a minimum of 8 inches in thickness. The pavement structure should consist of a Base Course a minimum of 6 inches in thickness, constructed in lifts not to exceed 3 inches each, overlain by a Top Course a minimum of 2 inches in thickness, designed and constructed in a manner consistent with the technical standards for Class I Bituminous Concrete in Section 460 of the Massachusetts Highway Department's *Standard Specification for Highways and Bridges*.

c) Sub-base – A suitable structural sub-base should exist or be provided to support an overlying concrete or bituminous pavement Isolation Layer, consistent with the technical standards outlined in Section 400 of *Standard Specification for Highways and Bridges*.

6.3.2 Separation Layer for Highly Toxic Hazardous Materials at a 1-4 Family Residence and for Chemicals with Severe/Lethal Health Effects

Additional isolation measures are necessary to ensure long-term isolation of highly toxic contaminants. The application and extent of these additional measures are a function of the toxicity of the contaminant and the nature of site activities and uses.

a) Highly Toxic Hazardous Materials - For the purposes of this guidance document, Highly Toxic Hazardous Materials are defined as those hazardous materials with a Human Toxicity Value equal to or greater than 35, as defined in the MCP at 310 CMR 40.1513.

At most sites, excavation and subsurface disturbance are controlled and/or regulated by commercial, industrial, or governmental entities. A similar degree of management is also exercised at collective residential housing, apartment, and condominium installations. However, external oversight and control is virtually non-existent at 1-4 unit residential dwellings. *For this reason, it is the Department's position that a stratum of soil or bituminous pavement cannot be considered an adequately protective Separation Layer for Highly Toxic Hazardous Materials at 1-4 unit residential dwellings*.

b) Chemicals with Severe/Lethal Health Effects – For the purposes of this guidance document, Chemicals with Severe/Lethal Health Effects are defined as those chemicals that have the potential to cause severe or lethal health effects from short-term or even one-time exposures, at the environmental concentrations present at the site of interest, as discussed in the MCP at 40.0926(3)(a)(2.). Chemicals that would meet this definition include, but are not limited to:

- oil and/or hazardous materials that in a single or short-term exposure of minutes to hours can cause injury to the skin, mucous membranes, or eyes to a degree that can threaten life, or cause permanent physical impairment or disability;

- oil and/or hazardous materials that in a single ingestion event or short-term inhalation exposure of minutes to hours can threaten life, or cause transient or permanent physical impairment or disability; and/or

- oil and/or hazardous materials with an oral LD_{50} value of less than 50 mg of chemical per kg of body weight.

For chemicals with severe/lethal health effects, it is the Department's position that a stratum of soil or bituminous pavement cannot be considered an adequately protective Separation Layer ***– at any site or location****.*

c) Design of Separation Layer – An acceptable Separation Layer in both of the above cases would be a cast-in-place slab of steel-reinforced, air-entrained Portland-cement concrete a minimum of 8 inches in thickness. The concrete slab should have a minimum 28-day compressive strength of 4000 psi, designed and constructed in a manner consistent with the technical standards outlined in Section 476 of the Massachusetts Highway Department's *Standard Specifications for Highways and Bridges*. If necessary, additional barrier elements should be utilized to protect or isolate the concrete layer from acidic or corrosive wastes or vapors.

6.4 DESIGN MODIFICATIONS

Alternative designs and/or materials for engineered barriers must be consistent and compliant with the performance standards articulated in 310 CMR 40.0996(4)(c).

Detailed below are design modifications and accompanying rationale that would be deemed acceptable by DEP. All other modifications must be fully discussed and defended in the Remedial Action Plan submitted for the site.

6.4.1 Alternative Design of Low Permeability Barrier

Based on information contained in *Design and Construction of RCRA/CERCLA Final Covers*, EPA/625/4-91/025, May 1991, the recommended USEPA landfill containment layer is a 0.5 mm (20-mil) Flexible Membrane Liner in intimate contact with a 24-inch layer of soil with a maximum hydraulic conductivity of 1×10^{-7} cm/sec. Using good construction practices, this design should ensure that infiltration of surface water through the containment layer will remain less than or equal to 1 gallon/acre/day. Accordingly, it is DEP's position that parties who do not elect to use one of the recommended design options in Section 6.2.3.2 of this policy should provide justification on the long-term equivalency to this standard, and/or otherwise demonstrate why the proposed containment layer is consistent with the performance standards outlined in 40.0996(4)(c).

While bituminous pavement and (Portland cement) concrete matrices are capable of achieving very low rates of hydraulic conductivity, overall performance and long-term functionality are of significant concern, due to cracks that develop from differential settlement and/or thermal expansion and contraction. For this reason, the use of such materials as a Low Permeability Barrier would generally not be considered protective by DEP unless complete and compelling documentation is provided which demonstrates a long-term level of infiltration control equivalent or superior to the recommended design options.

6.4.2 Elimination of Low Permeability Barrier

The incorporation of a Low Permeability Barrier into the design of an engineered barrier may be waived in those cases where adequate information, data, and rationale are provided to demonstrate (a) site contaminants will not significantly impact underlying and downgradient groundwater, (b) such a layer would not be effective, given the location of site contaminants (e.g., beneath the water table), or (c) such an installation is not otherwise necessary to achieve and maintain a condition of No Significant Risk.

a) Demonstration of a Lack of Significant Leaching Impacts – The following conditions and data could be used to rule out impacts of this nature:

- for organic contaminants:

  - the solubility limit of each compound present in soil above a UCL value is equal to or less than 20 times the groundwater standard(s) applicable at the site (i.e., GW-1, GW-2, and/or GW-3), as listed in 40.1514(2) or other appropriate source; OR

  - the soil/water partition coefficient (Koc) for each compound present in soil above a UCL value is equal to or greater than 10,000 mL/g; AND

- for inorganic contaminants present in soil above UCL values, all elutriate concentrations from TCLP or SPLP testing (as appropriate for site conditions) of representative samples are equal to or less than the groundwater standards applicable at the site (i.e., GW-1, GW-2, and/or GW-3); AND

- for organic and inorganic contaminants present in soil above UCL values, recent groundwater quality data from the site indicate that no such contaminant is present in the groundwater proximate to the impacted soils at concentrations equal to or greater than the standards applicable at the site (i.e., GW-1, GW-2, and/or GW-3).

b) Demonstration of a Lack of Effectiveness – A Low Permeability Barrier would generally not be considered effective or required by DEP if 90% or more of the mass of soil contaminants above UCL values are located below the mean water table elevation at the site. In such cases, however, adequate justification must be provided to demonstrate compliance with the source elimination requirements of 310 CMR 40.1003(5).

c) Other Considerations – In general, a Low Permeability Barrier should not be eliminated at sites where a Gas Vent Layer is necessary to contain and collect volatile emissions, and/or where such a layer is otherwise necessary to achieve and maintain a level of No Significant Risk.

6.4.3 Elimination of the Gas Vent Layer

The incorporation of a Gas Vent Layer into the engineered barrier may be waived in those cases where concern over the generation and buildup of toxic vapors and/or biogenic gases is eliminated through investigations and evaluations, which must be documented in the Remedial Action Plan. The following information and assertions would generally be sufficient to eliminate this phenomenon as a pathway of concern:

- there are no oil or hazardous materials present in soil at any location below the engineered barrier at a concentration equal to or greater than a UCL value with a vapor pressure equal to or greater than 0.5 mm Hg, as listed in 40.1514(2) or other appropriate source; AND

- there are and will be no oil or hazardous materials present at any location below the engineered barrier at a vapor-phase concentration equal to or greater than 100 times ambient (outdoor) air concentrations at the disposal site; AND

- there are and will be no levels of methane gas at any location below the engineered barrier at a vapor-phase concentration equal to or greater than 1% by volume.

6.5 SITE ISSUES

6.5.1 New Buildings

It is the Department's position that a new building may be placed over an engineered barrier and/or may be considered part of an engineered barrier ONLY under the following conditions:

- a geotechnical evaluation is conducted and documented in the Remedial Action Plan which demonstrates that placement of the building and foundation elements in the manner proposed will not compromise the integrity or adversely impact the long-term functionality of the engineered barrier; AND

- utilities and other subsurface conduits and structures servicing the building are not placed within or beneath the engineered barrier, as further detailed in Section 6.5.3; AND

- a gas-venting layer is incorporated into the engineered barrier, except as provided in Section 6.4.3.

6.5.2 Existing Buildings

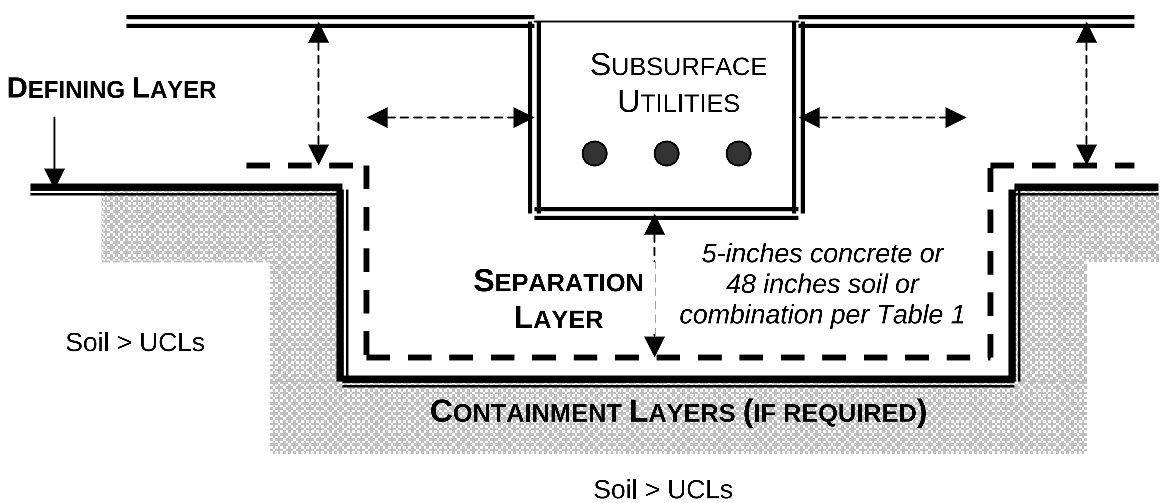
In accordance with the provisions of 310 CMR 40.0996(4)(c)(8.), an engineered barrier shall not include an existing building, unless and until it meets all requirements and performance standards applicable to newly constructed engineered barriers.

6.5.3 Utilities

Water, gas, sewer, drain, steam, electric, telecommunication, and other subsurface utilities and related appurtenances should not be placed or be allowed to remain within or beneath an engineered barrier. Adequate vertical and horizontal separation should be established between an engineered barrier and proximate utility structures to ensure the protection of workers and integrity of the engineered barrier during periods of future scheduled or emergency utility maintenance activities.

Preferably, subsurface utilities should be placed and/or relocated to areas of the property or disposal site outside the boundaries of the engineered barrier. Where this is not possible, placement within a “clean corridor” which completely surrounds the utility installation is recommended. Where unavoidable, utilities installed or located within soils containing concentrations of contaminants greater than Upper Concentration Limits (UCLs) must be completely surrounded by a Separation and Defining Layer, consistent with the requirements for engineered barriers, as detailed in Figure 3 (excluding subsurface drainage/gas piping integral to the engineered barrier). When necessary, this surrounding barrier must include Containment Layers, designed and constructed in a manner to provide needed drainage and/or gas conveyance.

Figure 3 – Recommended Subsurface Utility Placement within an Engineered Barrier



6.5.4 Re-grading and Consolidation

Soils containing concentrations of oil and/or hazardous material greater than applicable Upper Concentration Limits should NOT be moved to/consolidated on portions of disposal sites where concentrations of oil and/or hazardous material are lower than applicable Upper Concentration Limits.

6.5.5 Stormwater Management

Adequate systems must be designed and constructed to ensure the efficient and appropriate drainage of surface water run-on and run-off from that portion of the site containing the engineered barrier. However, the construction or use of storm water infiltration and/or detention ponds above or adjacent to an engineered barrier should not be allowed.

6.5.6 Signage/Markers

The use and placement of permanent signage and/or markers should be considered and implemented to the degree necessary and appropriate. In all cases, a detailed plan should be generated and archived documenting the locations and boundaries of the engineered barrier and related structures and appurtenances.

7.0 REFERENCES

1. MADEP, *Massachusetts Contingency Plan*, 310 CMR 40.0000.

2. MADEP, *Hazardous Waste Regulations*, 310 CMR 30.00.

3. MADEP, Landfill Technical Guidance Manual, revised May 1997.

4. USEPA, *Design and Construction of RCRA/CERCLA Final Covers*, EPA/625/4-91/025, May 1991.

5. USEPA, Region I, *Revised Alternative Cap Design Guidance Proposed for Unlined, Hazardous Waste Landfills in the EPA Region I*, February 5, 2001.

6. USEPA, *Evaluation of Subsurface Engineered Barriers at Waste Sites*, EPA 542-R-98-005, August 1998.

7. US Army Corps of Engineers, Cold Regions Research and Engineering Laboratory*, Frost Resistance of Cover and Liner Materials for Landfill and Hazardous Waste Sites*, Special Report 97-29, December, 1997.

8. National Institute of Standards and Technology*, Long Term Performance of Engineered Concrete Barriers*, NISTIR 5690, July, 1995.

9. Massachusetts Highway Department, *Standard Specifications for Highways and Bridges*, as updated.

Appendix

Evaluation of Subsurface Engineered Barriers

EPA 542-R-98-005, August 1998

http://clu-in.org/

Evaluation of Subsurface Engineered Barriers, EPA 542-R-98-005, August 1998

TABLE 4-1
MATRIX FOR EVALUATING CAP DESIGN AGAINST ACCEPTABLE INDUSTRY PRACTICES

Design Items	Less Than Acceptable	Acceptable	Better Than Acceptable
1. Global Waste Stability			
General		Check reliability of input data	Sensitivity analysis on waste properties
Under cap loads	None performed	Computer modeling done	Sensitivity analysis
Seismic stability	Not performed	NOAA data used and pseudostatic analysis completed.	Sensitivity analysis
Construction loading	Not performed	Consider worst case short term loading conditions during construction, apply equipment and stockpile loads	Sensitivity analysis
2. Settlement Analysis			
Refuse materials	Not considered	Representative data used for analysis/estimate	Settlement plates included in monitoring plan
Foundation materials	Not considered	Traditional soil mechanics analysis completed	
Impact of differential settlement considered	Not considered	Impact on cover materials analyzed	
3. Stability of Cap System			
Interface stability analysis	No analysis performed or analysis performed using assumed data	Analysis performed using data generated from laboratory testing of site specific geosynthetics and soils	Analysis performed with additional sensitivity checks performed
Cover soil tension above geomembrane lined slope	No analysis performed	Analysis performed to determine need for tension reinforcement using appropriate laboratory generated data	
Stresses within cap components	No analysis performed	Analysis performed using cap loads and construction loads	
Impact of differential settlement on geosynthetics	No analysis performed	Calculate stresses in geosynthetics due to subsidence	
Stability of slopes steeper than 3:1	Not considered	Slope protection designed	

Evaluation of Subsurface Engineered Barriers, EPA 542-R-98-005, August 1998

TABLE 4-1
MATRIX FOR EVALUATING CAP DESIGN AGAINST ACCEPTABLE INDUSTRY PRACTICES (Continued)

Design Items	Less Than Acceptable	Acceptable	Better Than Acceptable
4. Drainage Analysis			
Drainage capacity of cover system evaluated (transmissivity)	No analysis performed	Evaluate drainage requirements of cap system using models such as HELP and size drainage medium accordingly	
Geotextile filtration	No analysis performed	Evaluate cover soil compatibility with separation geotextile to prevent clogging and encourage filtration	
Runoff control	No analysis performed	Evaluate piping and discharge structure requirement for appropriate peak storm	
Erosion potential	No analysis performed	Universal soil loss equation used	
5. Leachate Management			
Leachate generation rate	Not considered	Analysis completed using site-specific data	
Collection/treatment system	Not considered	Collection/treatment system designed and documented	
6. Gas Management			
Well design/placement	Not considered	Pilot data from site used as design basis	
Passive system design	Not considered	Lateral piping and vertical vents designed	
7. Miscellaneous/Other Items			
Frost depth	Not considered	Soil barrier layer placed beneath maximum frost depth	
Puncture vulnerability	Not considered	Potential for waste material and cover soil to puncture cap system evaluated	

Evaluation of Subsurface Engineered Barriers, EPA 542-R-98-005, August 1998

TABLE 4-2
MATRIX FOR EVALUATING CAP CQA/CQC AGAINST ACCEPTABLE INDUSTRY PRACTICES

Category	Less than Acceptable	Acceptable	Better Than Acceptable
BORROW SOIL (Subgrade & Cover Soil)			
Soil Prequalification Testing:			
Classification ASTM D2487	Not performed	1 test per 5,000-6,580 c.y.	More frequent
Compaction Curve ASTM D698/D1557	Not performed	1 test per 5,000-6,580 c.y.	More frequent
Soil Construction Testing:			
Density Testing/Lift ASTM D2922/1556	Not performed	5 per acre	More frequent
Moisture Content Testing/Lift ASTM D3017/2216	Not performed	5 per acre	More frequent
COMPACTED CLAY LINER			
Clay Prequalification Testing:			
Classification ASTM D2487	Not performed	1 test per 5,000-6,580 c.y.	More frequent
Compaction Curve ASTM D698/D1557	Not performed	1 test per 5,000 c.y.	More frequent
Remolded Permeability Test ASTM D5084	Not performed	1 test per 10,000-13,160 c.y.	More frequent
Clay Test Pad Construction/Testing/Evaluation	Not performed	Not performed	Performed and well documented
Clay Construction Testing:			
Compaction Curve ASTM D698/D1557	Not performed	1 test per 5,000 c.y.	More frequent
Density Testing/Lift ASTM D2922/1556	Not performed	5 per acre	More frequent
Moisture Content Testing/Lift ASTM D3017/2216	Not performed	5 per acre	More frequent
Undisturbed hydraulic conductivity ASTM D5084	Not performed	1 per acre per lift	More frequent
Atterberg Limits ASTM D4318	Not performed	1 per acre per lift	More frequent
Grain Size ASTM D422	Not performed	1 per acre per lift	More frequent
Undisturbed Dry Density	Not performed	1 per acre per lift	More frequent
SOIL DRAINAGE LAYER			
Prequalification Testing			
Grain Size Analysis ASTM D422	Not performed	1 per 1,500-2,630 c.y.	More frequent
Hydraulic Conductivity ASTM D2434	Not performed	1 per 2,630-3,000 c.y.	More frequent
Carbonate Content Testing ASTM D4373	Not performed	1 per 2,630-3,000 c.y.	More frequent
Construction Testing			
Grain Size Analysis ASTM D422	Not performed	1 per 2.5 acres	More frequent
Hydraulic Conductivity ASTM D2434	Not performed	1 per 7.5 acres	More frequent
Carbonate Content Testing ASTM D4373	Not performed	1 per 2,630 c.y.	More frequent

Evaluation of Subsurface Engineered Barriers, EPA 542-R-98-005, August 1998

TABLE 4-2
MATRIX FOR EVALUATING CAP CQA/CQC AGAINST ACCEPTABLE INDUSTRY PRACTICES

Category	Less than Acceptable	Acceptable	Better Than Acceptable
GEOMEMBRANE BARRIER			
Manufacturing Quality Control Testing			
Resin Testing:			
Melt Index ASTM D1238	Not performed	1/180,000 lbs	More frequent
Resin Density ASTM D1505	Not performed	1/180,000 lbs	More frequent
Environmental Stress Crack ASTM D1693/5397	Not performed	1/lot(1,800,000 lbs)	More frequent
Compliance with NSF 54 Standard	Not performed	Performed	---
Geomembrane Conformance Field Testing:			
Thickness, Tensile, Elongation, Puncture, Tear	Not performed	1/100,000 s.f. - 1/lot	More frequent
Construction quality Control Inspection:			
Material Delivery Inspection	Not performed	Every roll	More frequent
Material Handling and Storage Inspection	Not performed	Every roll	More frequent
Pre-deployment Panel Layout Diagram	Not performed	Every roll	More frequent
Pre-deployment Written Subgrade Inspection Certificate	Not performed	Every roll	More frequent
Construction Quality Control Seam Testing:			
Trial Seams Testing	Not performed	a.m. & p.m.	More frequent
Non-destructive Seam Testing:			
Vacuum Box on Extrusion Welded Seams	Not performed	100% of seams	---
Air pressure testing on Fusion Welded Seams	Not performed	100% of seams	---
Destructive Seam Testing:			
Peel and Shear Testing ASTM D4437, D3083, D751	Not performed	250-750 linear ft. of seam	More frequent