National Guidelines for Hazardous Waste Landfills

PN 1365

Canadian Council of Ministers of the Environment

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Abstract

This guideline document has been commissioned by the Canadian Council of the Ministers of the Environment to establish current guidelines for engineered hazardous wastes landfill facilities.

The guidelines are intended to provide a reference on the basic design, operating and performance requirements for use by the various federal, provincial and territorial regulatory agencies, and designers, owners and operators of engineered hazardous waste landfill facilities in Canada. They are not intended to be a state-of-the-art technology review as this information can be obtained by reference to some of the many publications cited in the bibliography. Nor are they intended to replace professional technical expertise in the various specialized disciplines involved in the field of hazardous waste landfilling.

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Executive Summary

The design of engineered hazardous waste landfill facilities is an evolving science. Over the past decade, it has been substantially advanced through a growing appreciation of the need for a sound design comprising environmental and "engineered" components to contain or control the movement of contaminants. Invaluable experience and knowledge in every facet of landfill design, construction and operation is being used to improve the long-term performance of landfill systems.

An engineered hazardous waste landfill facility is part of an overall integrated hazardous waste management system. Disposal in an engineered hazardous waste landfill facility represents the final stage in the treatment and/or waste handling process, providing long-term confinement or control of hazardous materials as necessary for their effective contaminating lifespan.

The contaminating lifespan of some hazardous wastes pose significant challenges to landfill design and operation. Contemporary landfill designs are thought to need effective lifespans approaching 1,000 years, which is an estimated contaminating lifespan for persistent hazardous wastes. Estimated contaminating lifespan for a specific hazardous waste landfill will be dependant on the hazardous wastes the facility is designed for. Such longevity is difficult to achieve in landfill designs, but this is nonetheless an important factor in the design of an engineered hazardous waste landfill facility as an integrated hazardous waste management system.

These Guidelines are a model set of technical requirements. They come into effect only if adopted, in whole or in part, by a jurisdiction of authority. Even where these Guidelines have been either completely or partially adopted by a jurisdiction of authority, the application of the guidelines are subject to any restrictions or conditions that are in place or could be added by that jurisdiction of authority. Readers of these Guidelines should check with the jurisdiction of authority to see whether any of these Guidelines currently apply. The specific requirements of the applicable jurisdiction of authority should be incorporated into the design and operation of the engineered hazardous waste landfill facility.

An engineered hazardous waste landfill facility design includes a combination of natural protection and engineered systems that work together to contain or control the waste. The attributes of a natural environment may be used in place of engineered systems if they achieve an equivalent level of protection for the environment and human health.

The selection of a natural setting that can effectively control contaminant migration for many years can be a significant component of the engineered hazardous waste landfill facility. The site selection process should also have regard for the proposed engineered systems required for an acceptable landfill design. The site assessment needs to consider the appropriateness of these components within the natural environmental setting.

In terms of the engineered components, the limited service lives of such components are an important consideration in the facility design. Engineered components need to be used in combination with natural protection of the site setting to contain or control the escape of contaminants for the contaminating lifespan of all wastes.

Given the variations in climate and geology across Canada and the evolving nature of landfilling technology, some flexibility is needed in the application of these Guidelines. However, it must be demonstrated that any proposed approach ensures an acceptable level of long-term protection for the environment and human health.

A successful engineered hazardous waste landfill facility design depends upon an effective management strategy, with strict control over construction, operating and monitoring procedures by knowledgeable and competent staff. These procedures should be consistent with the general design philosophy of the landfill and provide for reasonably foreseeable conditions and incidents. Successful management of an engineered hazardous waste landfill facility is built upon objectively demonstrating and documenting the performance of every part of the facility and putting in place effective mitigative strategies.

While the active filling lifespan of an engineered hazardous waste landfill facility may be relatively short, the operation of a closed facility must continue until no threat of impact on the environment and human health remains. Since this timeframe can be considerable, the facility owner must ensure the long-term viability of the operation. This is typically done through financial assurances posted at the outset and during the operation.

The engineered hazardous waste landfill facility selection and design processes are complex and consider myriads of issues. Sound operation of the facility over the contaminating lifespan is equally challenging. A flexible and adaptive design and operation are considered to be important to the longevity of an engineered hazardous waste landfill facility and its ability to capitalize on future innovations as this technology progresses.

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Introduction

1.1 Scope

This document presents the national guidelines for *"engineered hazardous waste landfill facilities"*. It updates and replaces the 1991 CCME *National Guidelines for the Landfilling of Hazardous Waste*. These Guidelines are for the use of regulatory agencies and of hazardous waste management system designers, owners and operators. The topics considered include:

- wastes characteristics affecting landfill design,
- site selection,
- design and construction,
- operations and performance monitoring,
- closure and post-closure care,
- contingency and mitigation planning, and
- financial assurances and record keeping.

These Guidelines are a model set of technical requirements (*"criteria"*) and only come into effect if adopted, in whole or in part, by an authority having jurisdiction ("*jurisdiction of authority"*). Where these Guidelines have been adopted, in whole or in part, by a jurisdiction of authority, the application of the guidelines are subject to any restrictions or conditions that are in place or could be added by the jurisdiction of authority. These jurisdictions of authority requirements may change with time. Readers of these Guidelines are therefore advised to check with the federal, provincial or territorial authority having jurisdiction to see whether any of these Guidelines apply.

The Guidelines are intended primarily for new, engineered hazardous waste landfill facilities, not existing ones, but should also be considered for any engineered hazardous waste landfill expansion including, but not limited to: an alteration, enlargement or extension an area or a volume; or approving / permitting additional hazardous waste types / classes waste for disposal in an existing facility.

These Guidelines do not apply to radioactive waste landfilling, which is regulated by the Canadian Nuclear Safety Commission.

The intent of these Guidelines is to provide a framework of principles, methodologies and *criteria*. If adhered to, these Guidelines will minimize the risks posed by hazardous waste landfilling to the environment and human health. Technical details associated with the Guidelines are included in the appendices.

Given the variations in climate and geology across Canada and the evolving nature of landfilling technology, some flexibility should be allowed in the application of these Guidelines. However, any approach should be in compliance with the intent of this document, and should ensure an acceptable level of long-term protection for the environment and human health.

1.2 Overview of an Integrated Hazardous Waste Management System

Before considering the Guidelines for an engineered hazardous waste landfill facility, it is useful to describe how landfilling fits into an integrated hazardous waste management system.

1.2.1 Overall System

Since hazardous wastes have harmful properties, it is important to minimize the amount of hazardous waste requiring disposal. This can be achieved by

- reducing the amount of hazardous waste produced,
- reusing or recycling as much as possible of the waste, or
- recovering energy from the waste, or
- treating or otherwise destroying the waste.

If landfilling is necessary, the wastes must be suitable for land disposal or they must be modified to an appropriate form. This modification may be biological, chemical and/or physical, and may include thermal destruction.

Pre-treatment is outside the scope of this document. However, individual jurisdictions of authority should be consulted regarding their requirements (if any) regarding pre-treatment for specific wastes/parameters prior to landfilling.

There are typically five stages in a hazardous waste management system.

Stage 1: Waste Generation

The waste generation stage is the actual production and short-term accumulation of hazardous wastes on the site where the waste is generated. Wastes that are not suitable for reduction, reuse, recovery, recycling, or destruction may require treatment prior to land disposal in subsequent stages.

Stage 2: Waste Collection and Transportation

If the wastes cannot be used or treated at the waste generation site, they are collected and transported to the processing or disposal facilities.

Since hazardous waste should not accumulate in large quantities at a waste generation site for an extended period of time, hazardous wastes should be regularly collected and transported to an approved transfer station or to a central processing facility. Most jurisdictions of authority have their own regulations covering the licensing and approvals of transfer stations.

Hazardous wastes are normally sorted before they are processed further. This sorting is done either at an approved transfer station or at the central processing facility.

If wastes are initially sent to a transfer station, then the next step is further transportation of the wastes to the most appropriate central processing or disposal facility.

Stage 3: Waste Processing

At an appropriate facility, the waste may be processed to make it suitable for final disposal. This processing may include minimizing or eliminating hazardous properties, stabilizing the waste, and/or reducing its volume. The treatment could involve biological, chemical or physical processes (including thermal destruction) used either alone or in combination. The ultimate products of these processes will be

- non-hazardous gases or vapours (i.e., treated emissions),
- non-hazardous materials that are dissolved or suspended in water (i.e., treated effluents), and/or
- non-hazardous solids (including dusts).

Some of the products of these processes may be rendered less hazardous, inert or stabilized, while others may still remain hazardous and require disposal at an engineered hazardous waste landfill facility.

Stage 4: Residue Transportation

The hazardous residues that are suitable for safe land disposal are transported to an engineered hazardous waste landfill facility.

Stage 5: Waste Land Disposal

Wastes retaining their hazardous characteristic(s) are deposited in an engineered hazardous waste landfill facility as wastes along with waste collected from Stage 2, if suitable for landfill disposal.

There are various choices for the locations of these five stages in a good hazardous waste management system. A very large industrial complex may have all these stages located on its own property. Alternatively, any one or more of the stages may be located on separate sites.

1.2.2 The Landfill Component

This document is concerned primarily with Stage 5. More specifically, it provides guidelines for the disposal of the hazardous wastes in an engineered hazardous waste landfill facility, whether residuals that result from the processes in Stage 3 or from other sources. The characteristics of these residuals are important factors in hazardous waste landfilling to prevent contaminant impact(s).

After hazardous waste is deposited in an engineered hazardous waste landfill facility, there are many ways that potentially hazardous compounds can be released to humans or to the environment. The main pathways for release (as shown in Figure 1) are the following:

- emission of gases or vapours into the atmosphere from the wastes in the landfill,
- lifting of fine particles into the air by winds, leading to contamination of the atmosphere with hazardous dust,
- migration of water-borne hazardous materials through the soil, groundwater or surface water, leading to contamination of soil or water outside the disposal site, and
- direct exposure of people or wildlife to hazardous materials through a breach in the security of the containment system on the site (this includes the exposure of workers to waste materials through poor industrial hygiene and occupational practices, as well as the migration of hazardous materials off the site on worker clothing, by transportation on vehicles, and other inadvertent means).

All of these pathways should be effectively controlled by sound engineered hazardous waste landfill facility design and operations, monitoring, closure and post-closure plans.

The site selection, design, operation and closure specifications of an engineered hazardous waste landfill facility should consider both the short- and long-term effects of the facility on the environment and human health. The potential for waste discharge from the facility should be minimized. Moreover, the wastes themselves may need to meet strict specifications so that the impact of the landfilled waste is minimized.

Monitoring of the potential pathways to the environment should be carried out prior to construction (to obtain baseline information), during the operation, closure and post-closure

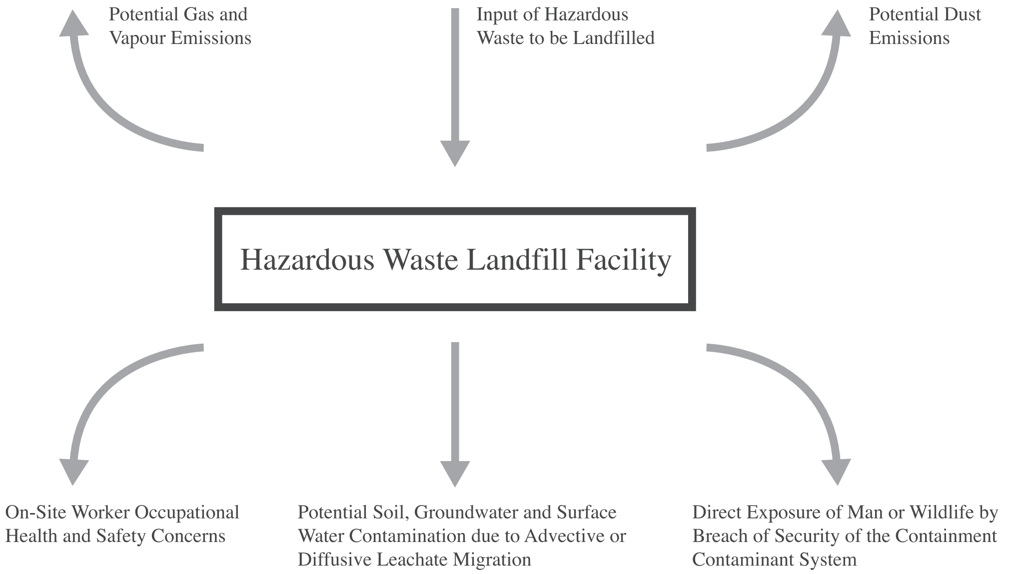

Figure 1. Schematic diagram of potential release pathways for material from a hazardous waste landfill.

periods. This monitoring should take into account the expected effects and the predicted time to the peak impact. This prediction is estimated by considering the contaminant quantity and quality, the contaminant fate and the long-term mobility of the contaminants in the waste, as well as the service life of the engineered components of the system. This prediction should be updated regularly throughout the contaminating lifespan of the facility as new monitoring data becomes available. Contingency planning should be developed and then put into effect if the monitoring detects problems.

In addition, financial assurances should be in place to isolate the public from financial and environmental losses. Assurances may take the form of cash, letter of credit, trusts, bonds or other equivalent financial arrangement as is deemed acceptable by the jurisdiction of authority (see Section 8 of the Guidelines).

The general factors that will reduce the potential effects on the environment include

- selection of an appropriate site,
- control of the material placed in the engineered hazardous waste landfill facility,
- enhancement of containment and leak detection through the use of engineered systems,
- long-term monitoring of the potential release pathways, and
- effective planning for contingencies.

Selection of a site in an appropriate environment is a key element to the long-term performance of an engineered hazardous waste landfill facility. Any releases from the facility during operation or the post-closure period should not result in deterioration of the surrounding ecosystems and should not adversely affect human health. However, this selection process deals with more than just an evaluation of the environmental setting and can include numerous other related factors such as municipal infrastructure. Compatibility with all aspects of the siting process is sought. A discussion of the site selection process is contained in Section 3 of the Guidelines with specific technical requirements provided in Appendix A.

Control of the material placed in the engineered hazardous waste landfill facility includes reducing the amount of leachate generated and minimizing the hazardous nature of the leachate. The amount of leachate can be reduced, for example, by not allowing the disposal of free liquids in the facility. Reducing the hazardous nature of both the waste and the resulting leachate is an important concept in landfill design and operations. A discussion of these issues is contained in Section 2 of the Guidelines.

Conceptually, the best possible engineered system in the most favourable natural environment is sought. Realistically, an acceptable level of protection to the environment and human health is required as defined by the jurisdiction of authority. This protection level is achieved using a favourable environmental setting supported by the necessary engineered systems. An engineered hazardous waste landfill facility design considers both the natural setting and engineered systems to contain or control contaminant migration. The attributes of a natural environment may be used in place of engineered systems if they achieve an equivalent level of protection for the environment and human health.

Engineered systems for engineered hazardous waste landfill facility design, operation and closure can improve the containment or control of the hazardous waste and its leachate. These systems may include a leachate collection system, soil or man-made liner materials, leak detection systems and cover systems. However, such systems should only be considered in conjunction with a good hydrogeologic environment, since the contaminating lifespan of the wastes is frequently longer than the lifespan of the engineered systems. Some engineered systems, such as a final cover, will be part of all engineered hazardous waste landfill facilities. Engineered systems are addressed in Section 4 of the Guidelines, with technical requirements provided in Appendices E, F, G and J.

Viable contingency measures and long-term monitoring of potential release pathways are required to provide an acceptable degree of protection to the environment and human health. Monitoring the integrity of the engineered hazardous waste landfill facility components, the engineered systems and the natural environment for potential contaminant movement is the key performance requirement. Contingency planning and monitoring requirements are discussed in Sections 5 and 6 of the Guidelines and in the Appendices.

1.3 Approaches to Developing Guidelines

As noted, these Guidelines are a model set of technical requirements. The Guidelines will discuss “measures of performance” or criteria in regard to the engineered hazardous waste landfill facility design, construction, operation and closure. These discussions about criteria should not be confused with *“standards”* which have a legislative cognition in many jurisdictions of authority.

1.3.1 Types of Criteria

In developing these National Guidelines for the disposal of hazardous wastes by landfilling, types of criteria were considered for different aspects of design, construction, operation and closure of an engineered hazardous waste landfill facility. Such criteria may be divided into three general categories:

- **Landfill siting, design and operating criteria,** which specify equipment, design features and procedures for the operation of the facility,
- **Performance criteria,** which specify minimal levels of performance of the facility, and
- **Risk assessment criteria,** which specify acceptable levels of risk to the environment or human health.

An example of **landfill siting, design and operating criteria** would be a requirement to incorporate a specific liner with specified characteristics (e.g., a composite liner consisting of a 2 mm thick HDPE geomembrane and a 0.75 m thick compacted clay liner with a hydraulic conductivity less than or equal to 10^{-9} m/s) or a specific liner system (e.g., a composite double-lined system that incorporates a leachate collection system and leak detection system) for a given environmental setting. Using such criteria offers a number of advantages:

- the criteria are relatively straightforward and easily understood,
- the criteria can be readily used by the owners, the designers and the jurisdiction of authority, and
- the criteria can be written so that they are reasonably easy to interpret and enforce.

Some of the criticisms of this approach are the following:

- such criteria discourage the development and application of new technology,
- such criteria are inflexible and make no allowance for the possibility that other criteria may be more appropriate for different circumstances,
- such criteria may not be easily transferable to all potential design configurations and landfill sizes, and
- when applied retroactively to existing facilities (that are already operating well), these criteria may not be necessary or economically feasible to apply.

To answer these criticisms, some jurisdictions of authority have allowed the use of "comparable" or "equivalent" approaches. Approval of an equivalent approach typically requires that the proponent demonstrate, to the satisfaction of the jurisdiction of authority, that the technology consistently achieves an equivalent level of performance.

Performance criteria can be divided into a number of categories:

- *Technical performance criteria,* which specify that the landfill should meet certain technical requirements (an example would be that all stormwater should be handled without mishap for a specified storm intensity and storm return period),
- *Containment performance criteria,* which specify that a certain level of containment or control should be achieved by the landfill (an example would be that a double-liner leachate collection system should not allow leakage through the primary liner in excess of a specified rate), and
- *Environmental performance criteria,* which specify a maximum allowable contaminant level in the environment around the landfill (an example would be that the contaminant concentration in the groundwater at a particular location should not exceed a specified level).

Performance criteria overcome a major disadvantage of design and operating criteria in that they allow the application of innovative technology. However, performance criteria have also been criticized, since they may require revision whenever new information is developed on the effects of hazardous wastes on the environment or human health.

Risk assessment criteria are based on the "degree of hazard" at a landfill and the corresponding risk ("exposure") to the environment and human health. They usually take the form of requirements for a specified acceptable level of risk.

1.3.2 Approach Used in these Guidelines

A number of factors were considered in the development and application of national guidelines for engineered hazardous waste landfill facilities in Canada:

- With respect to siting, these Guidelines apply specifically to the establishment of engineered hazardous waste landfill facilities,
- The climate, geography, geology, hydrogeology, ecology, population and land use varies markedly across Canada, and even in different areas of the same province or territory,
- The primary jurisdiction of authority for the treatment and disposal of hazardous wastes lies with the provinces and territories, and
- Technologies for the treatment and disposal of hazardous wastes are being modified and improved continually.

It is assumed that the establishment of any engineered hazardous waste landfill facility in Canada will be an undertaking unique to the area. Each landfill site may require a customized approach to address specific project conditions. These Guidelines use an approach to landfill design that includes a combination of natural protection and engineered systems (specially designed and manufactured components that work together to contain or control the waste). This approach is called an engineered hazardous waste landfill facility. The Guidelines allow for flexibility of application so that project-specific needs can be accommodated. The jurisdiction of authority may specify additional criteria that apply to certain sites and operating conditions. Some jurisdictions may also require certain waste specifications prior to land disposal.

Specific design and operational criteria will provide owners, designers and jurisdictions of authority of engineered hazardous waste landfill facilities with some confidence in the expected acceptance and performance of the facility. However, these Guidelines also allow for flexibility that permits innovation and adaptation of the design, construction and operation of the engineered hazardous waste landfill facility to suit the specific project.

For an engineered hazardous waste landfill facility project, an overall program should be developed that addresses all the issues raised in this Guideline document. At the same time, flexibility should be maintained by adapting the Guidelines to project-specific circumstances, if it can be shown that these adaptations would result in equivalent or enhanced protection levels to the environment and human health.

Waste Factors Affecting Hazardous Waste Landfill Design Performance

2.1 Historical Aspects

Considerable quantities of liquid and solid hazardous wastes, both treated and untreated, have been landfilled in the past. Experience has shown that landfills have limitations and cannot handle some types of hazardous wastes very well. Consequently, regulations have been developed by jurisdictions of authority to control the disposal of hazardous wastes, which may include the prohibition of the land disposal of specific wastes.

In waste management, the specialization and segregation of waste streams has led to improved waste handling and reduced costs. Landfill designers try to allow for these practices, but hazardous waste quantities are often limited and such specialization is not always feasible. Despite this, there are advantages to designing specific landfills for specific waste types instead of a single all-purpose landfill. For example, the performance criteria for landfills dealing with a wide spectrum of hazardous waste materials may have to be overly restrictive for some waste classes. Ideally, a balance is sought: an engineered hazardous waste landfill facility should maintain minimum operational, performance and risk criteria while remaining cost effective.

2.2 Rationale for Evaluating Waste Characteristics

Long-term integrity, reliability and operability are important factors for liner systems, leachate control systems and other engineered components of an engineered hazardous waste landfill facility. Both clay and synthetic liners can be damaged during placement of the wastes. In addition, the properties of clay and synthetic liners may be altered by contact with certain wastes (such as solvents) or by their chemical reaction with incompatible substances. It is essential in the engineered hazardous waste landfill facility design that the installed components and the waste materials be compatible.

Incompatible hazardous wastes should not be landfilled. To minimize leachate generation, liquids and materials containing free liquids should be minimized or excluded from engineered hazardous waste landfill facilities unless provision is made for their treatment within the facility.

Control of liquids should include control of liquids contained in absorbent materials. When these materials are placed under high pressures in the depths of the engineered hazardous waste landfill facility, the absorbed liquids may be “squeezed out” and become free liquids again.

Chemical reactions and the biological degradation of liquids can generate landfill gases. The potential adverse effects of these gases on the proposed engineered systems should be considered.

Containers such as drums, boxes and canisters should not be placed in engineered hazardous waste landfill facilities unless completely empty and devoid of liquids. They should be crushed, shredded or processed by some other means to reduce their volume. This will eliminate the uneven settling that can occur in the completed engineered hazardous waste landfill facility when containers collapse under the pressures experienced after burial. Uneven settling may threaten the integrity of the landfill cover, which would then need ongoing maintenance to ensure the security of the engineered hazardous waste landfill facility. The biodegradation of organic wastes poses the same settling problems. Care is required when considering this waste stream and in some jurisdictions of authority is subject to restrictions.

To protect the health of landfill workers and nearby residents, wastes may be prohibited from engineered hazardous waste landfill facilities if they have properties similar to those defined by the following regulations under the Transport of Dangerous Goods Act (Canada, 2002):

- Transportation of Dangerous Goods Regulations Class I–Explosives (August 2002),
- Transportation of Dangerous Goods Regulations Class IV–Flammable Solids, Substances Liable to Spontaneous Combustion and Substances that on Contact with Water Emit Flammable Gases (August 2002), and
- Transportation of Dangerous Goods Regulations Class V–Oxidizing Substances and Organic Peroxides (August 2002).

Explosive wastes, flammable solids, spontaneously combustible materials, water-reactive materials, oxidizers and organic peroxides pose the greatest threat to human health and operational safety in an engineered hazardous waste landfill facility. Such materials may create chemically unstable conditions if buried in an engineered hazardous waste landfill facility. Some jurisdictions of authority prohibit such wastes from disposal in landfills.

The characteristics of the wastes received should be confirmed prior to final acceptance and placement in the engineered hazardous waste landfill (waste acceptance procedures). Some jurisdictions of authority employ waste evaluation tests to determine the acceptability of wastes for land disposal. The specific requirements for the jurisdiction of authority should be incorporated into the engineered hazardous waste landfill facility design and operation.

Dilution or blending of a hazardous waste with a non-hazardous material should not be permitted for the primary purpose of dilution or to avoid the requirements for a regulation.

Hazardous wastes initially prohibited from landfills may be acceptable if sufficiently treated before disposal. Treatment or processing by the appropriate technology may be the most cost-effective means to handle certain waste streams.

The objective in applying treatment technology should be to minimize the potential release of contaminants to the environment if the security of the engineered hazardous waste landfill facility is breached. The possible methods, treatments or technologies that can be applied to hazardous wastes before landfilling include

- reduction of the volume and hazard level of the waste produced at the source (by modifying the industrial process that produces the waste),

- reuse, recycling of, and/or recovering energy from various components of the waste,
- physical and/or chemical treatments for separation of liquids and solids and to render them less hazardous,
- biological treatments for removal of biodegradable organic components,
- solidification, stabilization and/or fixation for converting liquid wastes to solid form and for encapsulating hazardous components, and
- thermal treatment for the destruction of organic wastes.

Leachate generated from treated hazardous waste residues can be hazardous. As is the case with treated hazardous waste, unless determined not to be hazardous, leachate generated from treated hazardous waste residues should be managed as a hazardous waste. Individual jurisdictions of authority should be consulted regarding their requirements.

Site Selection

A key factor to the success of the design for an engineered hazardous waste landfill facility is the site selection process. The selection of a natural setting that can effectively control contaminant migration for many years can be a significant component of the engineered hazardous waste landfill facility.

3.1 Site Location

An engineered hazardous waste landfill facility needs to be in a location with appropriate environmental conditions. These conditions are outlined in detail in Appendix A. An ideal site has a stable geological base, it is in an area that has little environmental sensitivity, and it is hydrogeologically appropriate.

An ideal site selection process provides a thorough understanding of the natural environment of the site. This allows the identification of potential contaminant pathways and potential human and environmental receptors of escaped contaminants.

The selection process is complex and considers a myriad of issues. The site selection process must evaluate all aspects of the natural environment, including its geology, hydrology, hydrogeology, biology, ecology, meteorology, air quality, archaeological, geotechnical and ambient noise.

An engineered hazardous waste landfill facility should be isolated from all significant surface water features such as creeks or ponds, so that the contaminant travel time will be based primarily on groundwater migration.

In addition, this process should consider numerous other equally important aspects including corridor or route selection, transportation, noise abatement, geotechnical and foundation engineering, buffer requirements, municipal and infrastructure planning and engineering, toxicology and socio-economics.

The site selection process should also have regard for the proposed engineered systems. The site assessment needs to consider the appropriateness of these components within the natural environmental setting. Aspects such as leachate collection systems, sewerage requirements, and the implementation of mitigation and contingency measures should be evaluated.

For contingency measures to be effective in the event of a contaminant release, an engineered hazardous waste landfill facility needs to be sufficiently isolated from nearby sensitive environmental features. The separation distance between the engineered hazardous waste landfill facility and an exclusion area should be based on the travel time of the contaminants along the preferred pathway whether groundwater, surface water or air. For a contingency measure to be viable, this separation distance must be large enough to allow time for a release to be detected and effective action to be taken before any damage is done.

The goal of all site selection studies is to gain a sound understanding of the environmental setting and the factors affecting this environment. This understanding is often referred to as the "Site Conceptual Model" and represents a simplified interpretation of the critical components of the environmental setting. With sufficient site knowledge, mathematical simulations of the physical site components (water and air movement) can be developed to assist in evaluation process. Other disciplines will use other types of models and analysis techniques such as GIS mapping.

The characteristics of each potential engineered hazardous waste landfill facility site are unique and may require a unique evaluation approach. This requirement defies the presentation of a standardized approach to the site selection process. However, it is necessary to evaluate all aspects (geology, biology, etc.) of the site setting for the design process. General guidelines for the site selection process are provided in Appendix A. Many jurisdictions of authority have specific site selection requirements that will supplement the guidelines provided above.

Site selection should be approached with two essential considerations: technical criteria and community acceptability.

Public participation should be an integral part of the project management plan from the outset. The input from local sources and all data should be made accessible and understandable to the general public. Decisions made in this process should reflect the public input.

Design and Construction

4.1 General Design Considerations

An engineered hazardous waste landfill facility is the final resting place for hazardous waste. It should be designed to prevent or control any effects of the waste on groundwater, surface water and air.

An engineered hazardous waste landfill facility design includes a combination of natural protection and engineered systems that work together to contain or control the waste. Most hazardous waste landfill sites are designed using this approach.

The components of the engineered systems will eventually fail: each has a specific "*service life*" (the length of time during which it will work as intended).

In addition, each engineered hazardous waste landfill facility will have a "*contaminating lifespan*" (the length of time during which contents of the landfill could still produce unacceptable levels of contaminants if a release occurred to the environment). Contemporary landfill designs are thought to need effective lifespans approaching 1,000 years, which is an estimated contaminating lifespan for persistent hazardous wastes. Estimated contaminating lifespan for a specific engineered hazardous waste landfill facility will be dependant on the hazardous wastes the facility is designed for.

The limited service lives of the engineered components of an engineered hazardous waste landfill facility should be considered in the design of a facility. Engineered components should be used in combination with natural protection[1] to contain or control the escape of contaminants for the contaminating lifespan of all wastes.

As a minimum requirement, an engineered hazardous waste landfill facility should be designed to not degrade the quality of groundwater or surface water such that they fail to meet a reasonable use for the water resource.

Any assessment of unacceptable impacts on the surrounding environment should include a definition of what is specifically meant by the phrase "unacceptable levels of contaminants" in terms of measurable quantities. An engineered hazardous waste landfill facility that does not meet the requirements noted above (or any more stringent requirement established by the jurisdiction of authority) would be considered to have an unacceptable impact. Points of compliance may be assigned on a site specific basis or may follow jurisdiction of authority requirements. The specific requirements for the applicable jurisdiction of authority should be incorporated into the engineered hazardous waste landfill facility monitoring program.

To meet the requirements identified above, two factors should be considered: the variability of the natural environment at the proposed site and the worst hazardous waste

[1] Natural protection is dependent on site selection (as discussed in Section 3).

expected at the facility (in terms of contaminant persistence, mobility and toxicity). At the outset of the design process, it will be essential to have accurate information on the geological and hydrogeological characteristics of the site and the surrounding environment (see Appendix B). These characteristics may have a profound influence on the overall integrity of the engineered hazardous waste landfill facility, as can the limited service life of the engineered components.

A comprehensive assessment of the natural environment (as described in Section 3) is required to design an engineered hazardous waste landfill facility (as outlined in Section 1). Despite this, the analysis of any natural setting should recognize uncertainties and limitations.

The development of a site conceptual model is based on the understanding and knowledge gained through the site assessment process. With sufficient site knowledge, a contaminant transport model can and should be developed to assist in estimating potential off-site environmental effects. The level of site knowledge needed to develop an accurate numerical model is considered to be consistent with the level of assessment required for an engineered hazardous waste landfill facility design.

An engineered hazardous waste landfill facility design should consider a contaminant transport model evaluation (based on a comprehensive site assessment), an assessment of the service life of the engineered components, and various other factors. This assessment may need to consider the degree of redundancy required in the system, the potential consequences of a facility failure, the effectiveness of contingency measures, and the relative merits of active and passive waste containment or control systems. The site assessment should be used to estimate the potential environmental effects of contaminants moving away from the engineered hazardous waste landfill facility over the entire contaminating lifespan of the wastes.

There are a few circumstances where the requirements identified above can be met solely by a landfill design using containment or control with natural materials on the site. Most engineered hazardous waste landfill facilities are designed as a combination of a favourable natural environmental setting with engineered systems (see Section 4.2).

4.1.1 General Layout and Security

An engineered hazardous waste landfill facility should have a layout that allows for safety, efficiency, security, monitoring and the implementation of contingency measures (if needed).

The layout of an engineered hazardous waste landfill facility should accommodate the physical setting of the site, the *"landfill development plan"*, access to roads outside the site and efficient traffic flow.

Within the legal boundary of the engineered hazardous waste landfill facility site, a buffer zone should be provided around the perimeter to act as a visual screen and a noise barrier among other functions. A buffer zone should also provide space around the perimeter of the waste area in which contaminant attenuation may occur, and various monitoring, maintenance and environmental control activities can take place. The buffer zone should be designed for the implementation of mitigative and/or contingency measures. The buffer zone should also contain a site access road, site services and buildings, groundwater monitoring wells and landscaping. The width of the buffer zone, the visual screen and the noise attenuation features may vary according to land use, local regulations and the proposed contingency systems (see Appendix B).

Access to the site should be strictly controlled. Both incoming and outgoing traffic should pass through a single control point for: manifest, movement document or shipping document verification; waste sampling; and any other regulatory or administrative actions. Appropriate signage, signals and lighting should be used to direct the flow of traffic on the site (see Appendix C).

4.1.2 Buildings and Facilities

The engineered hazardous waste landfill facility infrastructure will require buildings and facilities to support the facility's operations. Typical structural elements include administrative buildings, equipment and maintenance buildings.

All buildings should be protected from contamination by gas migration from the landfill. Their locations should not interfere with monitoring or with the implementation of contingency measures.

Specialized facilities may include access and patrol roadways, weigh scales, material storage areas for landfill cover materials or for load inspection, bays or pads for vehicle washing, security systems, testing laboratory, clean areas for staff to wash-up and eat, and emergency response equipment.

The engineered hazardous waste landfill facility operation should require access to a laboratory capable of providing rapid checks on the physical and chemical nature of the materials to be landfilled. If a chemical solidification, stabilization or fixation process is installed as part of the facility, then the capabilities of the laboratory can be expanded to include test work relating to the operation and quality control of that process. Wastes generated by the laboratory should be treated as hazardous wastes unless proven otherwise.

A transfer point for waste inspection (prior to disposal) should be provided on the engineered hazardous waste landfill facility.

The engineered hazardous waste landfill facility infrastructure should provide wash-up areas for personnel, external water supplies, sewage disposal, power sources including an on-site emergency supply, telephone and computer network services, and an above ground vehicle fuelling depot(s) with containment, if necessary.

The roadways at the facility should be designed for easy turning and manoeuvring, and have reasonably moderate grades. Road surfaces and load capacities should be compatible with the intended use, and should allow for inclement weather. Paved roads may be better for routes that will be used continuously over the life of the facility, since they will assist in dust control and provide an all-weather surface.

Any contaminated or potentially contaminated liquids and solids generated at the engineered hazardous waste landfill facility (such as collected stormwater, worker shower water, laundry water and vehicle wash water) should be segregated and managed as a hazardous waste unless proven non-hazardous.

Any contaminated water should be kept in lined detention ponds prior to treatment or disposal. On-site treatment facilities may be required to deal with contaminated stormwater and other water contaminated on the facility.

4.2 Engineered Systems

Engineered systems may consist of the additional protection of an engineered barrier system that has liners (see Section 4.2.1 and Appendix F) as well as leachate collection and detection systems (see Section 4.2.2 and Appendix G). All engineered systems should be evaluated using guidelines noted in Section 4.1 for the particular site and for the anticipated wastes.

An example of a representative engineered hazardous waste landfill facility is a double-lined system with two composite liners and two drainage layers in an appropriate environmental setting (see Figure 2). This barrier system can detect leakage through the primary liner and then collect most of that leakage in the "leak detection/recovery layer". However, this system requires active operation of the leachate collection layers as well as active monitoring of the engineered systems.

4.2.1 Liner Systems

Liners help to prevent the movement of liquids and hazardous materials from an engineered hazardous waste landfill facility into the groundwater systems. Liners also help to prevent the movement of landfill gases. The four main categories of liners are

- natural low-permeability clayey deposits,
- compacted clay liners,
- *"geosynthetic clay liners"* (GCLs), and
- *"geomembrane liners"*

Natural deposits may be more variable in their properties than engineered clay liners and contain natural fractures, therefore a greater thickness of natural material is typically required to allow for this.

Compacted clay liners provide good resistance to certain contaminants (such as organic compounds and heavy metals), but they readily allow the migration of others (such as salts). There is also a need to be aware of the chemical makeup of the clay that is used to ensure that there is limited to no chemical interaction between the leachate and the clay that could compromise the integrity of this liner material.

GCLs are very thin and must typically be used together with a layer of natural material to provide a good barrier to the movement of contaminants by *"diffusion"*.

Geomembranes are also very thin. They can develop holes and tears and allow leakage if the geomembrane is used alone. However, they provide an excellent barrier to liquids and to the diffusion of ionic contaminants (such as heavy metals and chlorides). Unfortunately, they readily allow the "diffusion" of many "*organic chemicals"*.

Each material has advantages and disadvantages, so two liners are often used together to form a composite liner. These are commonly constructed from a geomembrane and a compacted clay soil that are selected and installed to meet specific requirements. The advantages of one material are used to offset the disadvantages of another. For example, a composite liner consisting of a geomembrane and a compacted clay liner can provide an excellent barrier to organic

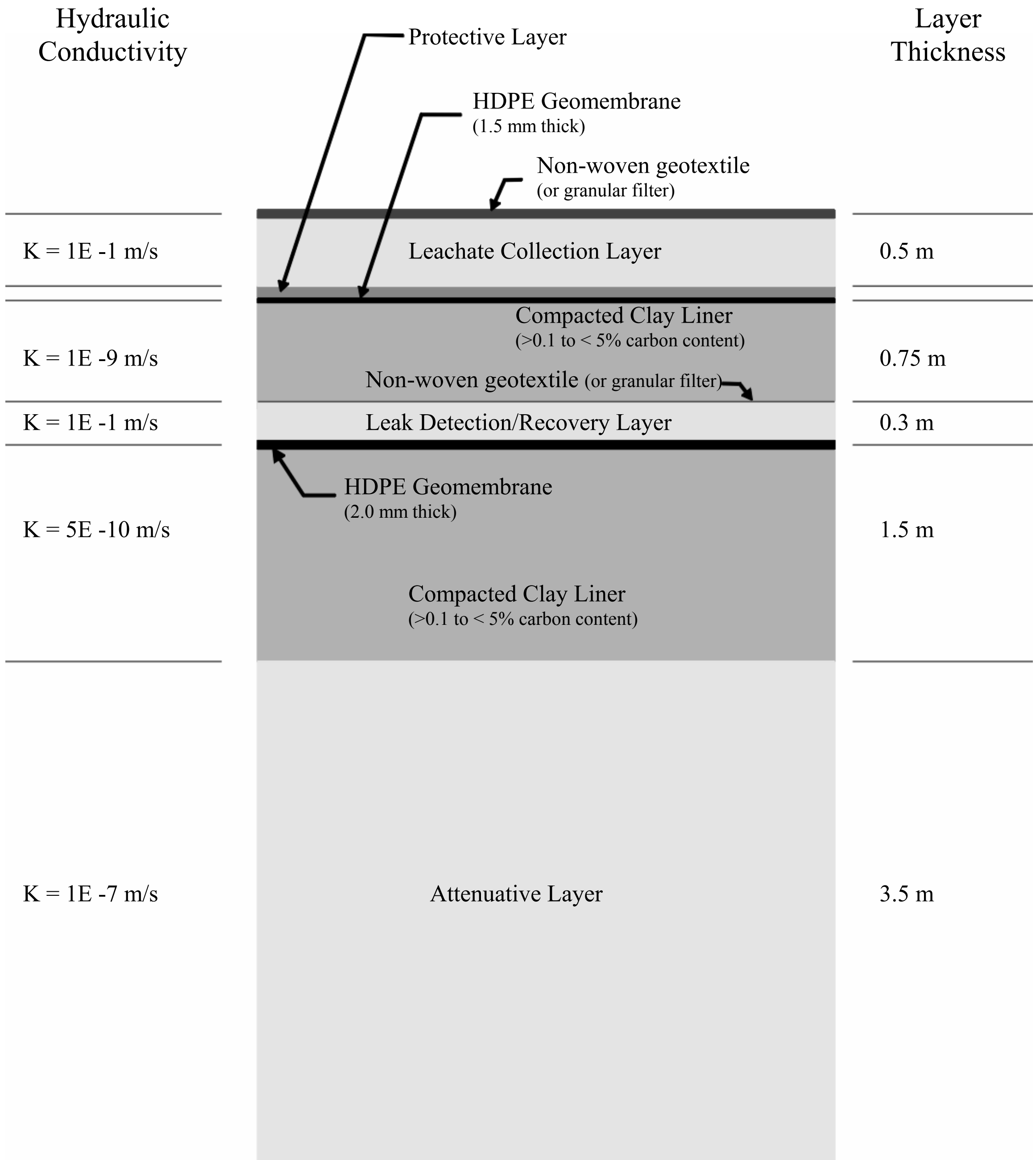

Figure 2. Example of a schematic profile of a composite double liner system for a hazardous waste landfill.

contaminants as well as heavy metals and salts. The combination of the two liners also substantially reduces the overall leakage as a result of the disadvantages in either one.

Often more than one composite liner system is used, as in the example shown in Figure 2. Any leakage through the upper (primary) liner system can be detected and removed before the contaminants can pass through the lower (secondary) liner system. In Figure 2, the upper liner system is a geomembrane plus a compacted clay liner, while the lower liner system is a second geomembrane, a second compacted clay liner, and a thicker layer of natural deposits.

Considerable care is required in the design and construction of the liner systems for engineered hazardous waste landfill facilities. Historically, soils with high clay content have served as liner material in many landfills, which may represent existing *in situ* clay soil (in the original position or site) if it happens to be in an excellent hydrogeologic environment. More commonly, however, composite liners are necessary using imported materials.

Often, the contemporary design standard for an engineered hazardous waste landfill facility is a double composite liner system with a natural attenuation layer (Figure 2). However, any engineered hazardous waste landfill facility design that can be shown to provide equivalent or better protection to the environment and human health and meets all jurisdiction of authority requirements is acceptable. Site conditions will dictate the degree of engineering required to obtain the facility design criteria.

Factors to consider in the design and installation of compacted soil liners should include (see Appendix F)

- the best moisture content for compaction of the clay,
- the thickness and the type of compaction of the compacted layers,
- the resistance of the liner materials to the migration of fluids (i.e., the *"hydraulic conductivity"* / permeability),
- the interactions between the clay and the contaminants to be retained, and
- the quality assurance and quality control procedures necessary for construction.

Factors to consider in the design and installation of a geomembrane and GCL liners should include (see Appendix F)

- the compatibilities with the hazardous waste, the leachate and the landfill gases;
- the resistance to weathering (e.g., by ultraviolet radiation);
- the resistance to physical damage;
- the resistance to rodents, insects and microbes;
- the resistance to chemical aging;
- the retention of specified properties at operating temperatures;
- the effectiveness and efficiency of making joints and seams;
- the quality assurance and quality control requirements for manufacture and installation; and
- the projected service life.

Among the many synthetic membrane liner materials available, HDPE (high density polyethylene) is presently the material of choice. HDPE exhibits good tensile strength and elongation properties, high tear and puncture resistance, good low temperature flexibility and excellent resistance to attack by a wide variety of hazardous materials.

Geomembrane liners should be designed and installed with adequate protection against the development of holes, tears, and cracks during construction and operation.

The design of an engineered hazardous waste landfill facility and specifically a liner system should follow geotechnical engineering principles for the construction of liners, dikes, cut slopes, landfill cells, and drainage structures (see Appendix F). The strength of both in situ soils and engineered soils should be assessed by appropriate laboratory and in situ testing. Safety factors for cut slopes and embankment slopes should be adequate for both short-term and long-term operation.

4.2.2 Leachate Control

The migration of liquid/water to and from a landfill is caused by differences in the liquid/water levels in the landfill and in the surrounding soil. If the liquid/water level in the landfill is higher than the level of the surrounding groundwater, then there is potential for the "*leachate*" to escape from the landfill. In this case, a liner can provide the primary barrier to contamination. If the liquid/water level in the landfill is below that of the groundwater outside the landfill, then there should be no outward flow of leachate from the landfill. There can also be cases where there is negligible difference in these levels, but these are unusual.

Unless measures are taken to control the leachate level in an engineered hazardous waste landfill facility, it will typically be above that of the groundwater system. The primary objective of a leachate collection system is to keep the leachate level as low as possible, and ideally below that of the surrounding groundwater system. This will minimize the risk of contaminant migration to the groundwater outside the engineered hazardous waste landfill facility.

To contain or control contaminant migration from the engineered hazardous waste landfill facility, a *"leachate management system"* may be developed for the facility (see Appendix G).

Leachate normally is collected above the uppermost composite liner and conveyed by a network of perforated pipes to sumps or riser pipes for surface containment and disposal. Design considerations for a leachate collection system are compiled in Appendix G.

A leak detection system can monitor the long-term performance of the primary collection and liner system. It also provides a means of collecting most of that leakage and therefore is a second leachate collection system. The construction requirements are similar to those of the primary leachate collection system (see Appendix G).

A leak detection and recovery system should be installed between the two composite liners to measure the leakage rate over time, to allow sampling and analysis of the leachate, and to recover the leakage. This information should be used to assess the ongoing performance of the primary composite liner.

The characteristics of the leachate from a new engineered hazardous waste landfill facility are relatively unpredictable. Sampling and analysis at a specific site will allow assessment of these characteristics (which should reflect the landfill waste composition). Leachate from an engineered hazardous waste landfill facility may be classified as hazardous waste.

Leachate can be difficult to treat and dispose of. The amount of leachate can be reduced by installing a suitable landfill cover or cap to reduce the water input (as discussed in Section 4.3). If the quantities of leachate are relatively small, a leachate treatment facility may not be needed on the engineered hazardous waste landfill facility and the leachate may be hauled to an appropriate waste treatment facility for processing. Unless it is determined not to be hazardous, any leachate or seepage collected from a hazardous waste landfill should be managed as a hazardous waste.

4.3 Engineered Cover

An engineered cover (also known as the *"final cover")* for an engineered hazardous waste landfill facility is designed to control, minimize or eliminate (as necessary to protect the environment and human health) the escape of any material from the facility to the ground, to surface waters or to the atmosphere. Unless determined not to be hazardous, these releases should be managed as a hazardous waste and may include landfilled waste, leachate, vapours/gases, contaminated runoff or decomposition products.

Engineered cover differs in function and form from daily and interim cover (Section 5.5). An engineered cover is intended to create an impervious barrier to prevent seepage into the landfill and from material escaping from within, thus isolating the landfill from the environment. Engineered covers also should

- control or minimize the entrance of liquids into a closed landfill cell,
- function with minimum maintenance,
- promote surface drainage,
- withstand erosion or abrasion, and
- accommodate settling so that the integrity of the cover is maintained.

An engineered or final cover system should be installed over each landfill cell to isolate the wastes, control water infiltration and provide erosion protection for the facility.

The barrier layer of the cover system should be joined securely to the landfill liner system at the perimeter of the landfill cells. The cover system should be thick enough that the damage from freeze/thaw cycles is minimized.

4.4 Stormwater Management

Proper stormwater management is an important consideration in the design and construction of an engineered hazardous waste landfill facility (see Appendix D).

Appropriate precautions should be taken to direct surface water (i.e., "run-on") away from the active area of an engineered hazardous waste landfill facility. Run-on from areas containing landfilled hazardous wastes should be collected separately, analyzed, and (if necessary) managed as hazardous waste. Run-on from active areas should be considered to be potentially contaminated, analyzed and (if necessary) managed as hazardous waste as well.

All designs to manage stormwater should be assessed for the potential effects of a repeat of the regional event (the largest storm on record).

4.5 Landfill Gases

The biodegradation of waste materials releases gases such as methane and carbon dioxide to the subsurface. While it is acknowledged that the release of gases from hazardous waste is generally low, an assessment of the potential of landfill gas generation and release to the subsurface should be completed.

Gas may be generated within landfilled wastes by the chemical reaction of incompatible waste materials or by the decomposition of *organic materials*[2]. Gases could result from the evaporation of volatile chemical wastes that are placed in a landfill. Incompatible leachates or incompatible waste materials that are generated at the landfill are other possible sources of gas generation. More difficult to forecast are the gases generated from aged or leached materials that have become chemically altered within the landfill. Furthermore, gas may be produced in some areas of the landfill and not in others. The nature and variability of hazardous wastes makes the prediction of gas generation generally uncertain.

The potential for gas production in the engineered hazardous waste landfill facility should be determined. Possible gas migration pathways in the subsurface layers of the natural environment should be evaluated.

Subsurface migration of landfill gases should be routinely monitored, especially if significant volumes of gas are being generated. Detected gas should be sampled to determine which waste(s) is the potential source(s) of the gas. This information should be used to devise mitigative strategies.
An appropriate contingency system for gas collection, treatment and release should be implemented, if needed.

[2] Section 2 of this document suggests that the disposal of organic material should be minimized in hazardous waste landfills.

4.6 Construction Quality Assurance Program

As part of any engineered hazardous waste landfill facility construction program, a construction quality assurance (CQA) program should be completed. Such a document should also be considered for an expansion of an engineered hazardous waste landfill facility including, but not limited to: an alteration, enlargement or extension of area or volume; or approving / permitting additional hazardous waste types / classes for disposal in an existing facility. All construction projects should have measurable performance specifications prior to construction. For the construction to be considered acceptable, these specifications should be achieved within predefined variation limits.

A new engineered hazardous waste landfill facility should not be constructed unless a written document has been prepared that describes the project in detail. Such a document should also be considered for an expansion of an engineered hazardous waste landfill facility including, but not limited to: an alteration, enlargement or extension of area or volume; or approving / permitting additional hazardous waste types / classes for disposal in an existing facility. This document should contain

- plans and specifications for the facility,
- procedures for monitoring and documenting the quality of the materials, and
- procedures for monitoring and documenting the installation of the materials.

The document should

- identify components and describe how they will be constructed;
- identify the key personnel who will develop and implement the CQA plan, and list the qualifications of the CQA officer;
- describe the inspection and sampling procedures for all construction materials and unit components (including observations and tests that will be used before, during and after construction);
- describe the sampling size, location, frequency, evaluation procedures, and acceptance and rejection standards (as well as any corrective measures to be taken, and any data or other information to be logged in the operating record); and
- specify quality assurance inspections, tests and measurements for the project.

The quality assurance inspections, test and measurements must be sufficient to ensure

- the structural stability and integrity of all components of the engineered hazardous waste landfill facility;
- the proper construction and installation of all parts of the liners, the primary leachate collection and removal system, the secondary leachate collection and leak detection system, and the final cover system;
- that all materials meet with the design specifications; and
- that the compacted soil liners meet the hydraulic conductivity requirements (using test pads with the same compaction methods as the full-scale unit).

Compliance with all specifications should be verified by appropriate testing.

Operations

5.1 Overview

The successful operation of an engineered hazardous waste landfill facility hinges on strict control over the procedures for operating and performance monitoring. These procedures should be consistent with the general design philosophy of the facility and provide for proper closure and post-closure care.

The operational strategy should be closely aligned with a standard environmental management system (EMS).

Specific jurisdiction of authority requirements should be identified when developing the operational plan for the proposed facility.

5.2 EMS Approach

An *EMS* can be defined as a group of methods and tools that align the strategies, policies, and operations of an organization with principles that are known to protect ecosystems. Five elements of an EMS are

- policy,
- planning,
- implementation and operation,
- testing and corrective action, and
- management review.

Proper application of this system becomes a cycle of continuous improvement.

An EMS is a systematic approach to the overall operational strategy

- The first step is to establish environmental policies for the operation.
- The operational plan is then reviewed and environmental performance objectives are defined for the system operations. Employee responsibilities need to be specified so that everyone is aware of their duties and those of their colleagues.
- The implementation phase requires introductory training programs and complete documentation of all the systems and procedures of the EMS.
- The EMS is tested during the initial operational phase. System processes are monitored or measured, and corrections are made to them as needed. (Auditing can be an effective tool).
- The final component is management review. The intent of this review is to permit decision-making and constructive policy changes, thus continuing the cycle of improvement.

Resources and expertise both inside and outside the facility should be recognized and used at appropriate times.

5.3 Administrative Procedures

A comprehensive facility-specific operating manual should be prepared for the engineered hazardous waste landfill facility (see Appendix G). This manual should be reviewed by all staff and used as the primary reference document for day-to-day operation.

The manual should be regularly revised and updated as new procedures are developed for environmental or regulatory conditions. This review and revision process is a scheduled activity within an EMS strategy.

A procedural manual should address all relevant details of the operation, including

- health and safety,
- waste manifests and movement documents,
- shipping documents,
- daily activity logs,
- public complaints and action(s) taken,
- performance and compliance monitoring,
- maintenance (including all corrective actions to be taken),
- training,
- public outreach,
- contingency management,
- emergency procedures, and
- reporting.

The manual should be written in a style and format that promotes its use as a reference tool. However, the manual is intended to provide guidance only and should not replace the good judgment of the facility staff. Training opportunities should include development of judgment skills.

A comprehensive inventory control and record-keeping system for waste materials should be established at the engineered hazardous waste landfill facility. This system should be strictly followed by all operating personnel.

The facility owner should ensure that all occupational health and safety problems associated with the facility operation are adequately resolved and properly documented. A comprehensive health and safety plan should be developed as may be required by the jurisdiction of authority.

The facility owner should ensure that all required personal protection equipment is readily available and is properly used by all persons entering the facility.

5.4 Waste Placement

Procedures for the handling of hazardous wastes take effect as soon as delivery vehicles enter the engineered hazardous waste landfill facility site.

Provision should be made to prevent potentially contaminated materials from being inadvertently transported away from the site by “tire-tracking” or other pathways.

Vehicles entering the site should off-load their cargo for waste inspection prior to disposal. Waste manifests or movement documents (as required by jurisdiction of authority regulations), are an important component of the cradle-to-grave tracking of the waste. Waste characterization to verify the waste that is being received at the facility typically includes waste sampling. Cargo inspections need to check the correctness of these manifest or movement documents prior to accepting the waste shipment.

After completing the shipment receiving procedures, the cargo should then be picked up and taken to the active landfill area by vehicles and equipment dedicated exclusively to working in the contaminated areas of the site.

The placement of hazardous wastes in the engineered hazardous waste landfill facility should be controlled and systematic. Waste placement procedures should consider the intended landfill concept (enhanced vs. conventional leaching), the cell design and the leachate control system (to prevent clogging), cell development requirements (to ensure physical stability), and capping and closure requirements (to minimize settling). They should also enforce the segregation of incompatible materials to minimize the risk of explosions, fires, and the evolution of toxic gases. Other considerations affecting waste placement include the effects of infiltration and of surface water flow into the active landfill area (see Appendix G).

Precise waste placement records should be maintained throughout the active facility filling. The waste placement plan should be tied into the site survey benchmarks. These records would be required if specific wastes needed to be extracted from the facility and would allow for accurate extraction of the waste in the future. The placement records can be used for a variety of other activities.

5.5 Daily and Interim Cover

Interim cover of a landfill is designed to improve safety factors, drainage, venting isolation, and protection of the foundation. Because hazardous materials are present as opposed to putrescible waste, engineered hazardous waste landfill facilities do not attract vermin and vectors (organisms that can carry diseases or other hazards) as readily as municipal facilities.

Daily cover is used to discourage and control such organisms if they do appear. Daily cover may also be required to minimize exposure of the surroundings to windblown odours, dusts, fire, or litter. A daily cover is effective at isolating the wastes from the environment when inadvertent reactions occur. In extreme cases, it can buffer severe spontaneous events such as explosions.

In the waste placement operations, the interim cover can be effective for waste isolation or separation. Similarly, the cover may be effective for dealing with infiltration, vapours and gases. The cover material may be used to provide physical stability and act as “fill” in void spaces between emplaced wastes to reduce settlement problems. Interim cover may be used to limit exposure of the waste cells to precipitation events, but such cover material would have to be more fine-grained than granular to be effective for that purpose.

The operations plan should account for the daily and interim cover requirements and required material stockpiles. Logistical issues such as winter use and freezing of the cover material should be addressed in the operations plan.

5.6 Leachate Collection, Leak Detection and Leak Recovery Systems

The leachate collection, leak detection and leak recovery systems are designed to remove essentially all the detected liquids that leach from the engineered hazardous waste landfill facility over its contaminating life span. A leachate collection system has a finite lifespan which may be significantly shorter than the predicted contaminating lifespan of the facility. Therefore, it would be advantageous to design a system that can be replaced as many times as required and with minimal effort. These active systems serve a dual purpose:

- minimizing the potential for contaminant migration and

- monitoring the effectiveness of the containment or control systems.

A system should be installed to remove pumpable liquids in the system and thus to minimize the liquid pressure at the bottom liner (Appendix G). The system requires an effective performance monitoring program that should be routinely evaluated. The monitoring program should trigger corrective actions if the system performance does not meet the minimum targets.

The jurisdiction of authority may require official approval of the performance criteria of these systems and of any later modifications.

Unless it is proven not to be hazardous, leachate from an engineered hazardous waste landfill facility should be considered a hazardous waste and managed accordingly.

5.7 Contingency Plan and Procedures

A set of contingency procedures should be prepared and updated on a regular basis. These would cover any reasonable and foreseeable emergency scenario. The plan should deal with mishaps both on-site and off-site that could affect public health and safety, the environment and property.

Contingency plans are traditionally tied into performance monitoring programs. Monitoring results outside of predefined limits "trigger" the need for contingency action(s) and the level of response required.

All staff should be trained to deal with such problems. Routine exercises or drills can be effective for preparing staff to conduct these procedures.

The owner of an engineered hazardous waste landfill facility should ensure that contingency plans are developed for all operational phases of the facility, including construction, operation, maintenance, replacement, closure and post-closure.

The contingency plan should include plans, specifications and descriptions for contingency measures and procedures that will be used at the facility (see Appendix G).

5.8 Emergency Procedures

An emergency procedures plan should be prepared and updated on a regular basis. This plan would cover less likely but more dangerous mishaps at the engineered hazardous waste landfill facility. It should be prepared in consultation with the jurisdiction of authority and local community emergency response authorities.

Changes to the emergency procedures may reflect amended jurisdiction of authority requirements, changes in personnel, technology, equipment or response procedures.

Emergency procedures deal with catastrophic events and those that involve imminent risk to the environment and human health. Examples include fires, explosions, accidental spills of contaminants in non-active areas, and the generation of unanticipated contaminated runoff, leachate or vapours.

The owner of an engineered hazardous waste landfill facility should ensure that emergency procedures are developed, documented and followed. The emergency procedures plan should include the following:

- an identification of the types of emergencies that might occur, together with on-site and off-site consequences,
- prevention, preparedness, response and recovery measures,
- descriptions of the ongoing training of each employee on the subject of emergency procedures, and the measurable results required for successful completion of each part of this training.

All staff should be thoroughly trained and routinely updated in emergency response procedures (see Appendix G). Staff should know their responsibilities in an emergency, where to get the required emergency equipment and supplies, and how to use these materials effectively.

The level of redundancy in staff training should be high enough that emergency responses are effective even in difficult circumstances.

A key component of an "events-related" plan is a good communication strategy. Successful decision-making in an emergency situation often depends on getting critical information. Effective staff management also needs good communication for tasks such as deployment, evacuation and information gathering. The emergency response team should be monitoring command communications to ensure that their actions are effective and that necessary information is transmitted quickly.

5.9 Personnel Programs

All personnel at the engineered hazardous waste landfill facility should undergo a comprehensive training program before and during their period of employment at the facility. Personnel should be tested and pass mandatory training programs appropriate to their job functions before being permitted to perform the work (see Appendix G).

Following the initial training programs, there should be regular refresher programs to reinforce established procedures and to introduce new procedures. Personnel records should be maintained to document the nature and timing of training completed by each employee.

Environmental Monitoring Programs

Environmental monitoring programs on and in the surrounding engineered hazardous waste landfill facility site area allow the owner and the jurisdiction of authority

- to establish baseline conditions at the site,
- to detect natural and/or external trends,
- to demonstrate that the facility is performing as designed (EMS testing),
- to identify any potential impacts on the surrounding ecosystem, and
- to comply with jurisdiction of authority requirements.

Environmental monitoring programs should be performed by trained staff (or professionals) and follow established sampling protocols. Different expertise is required to perform different types of monitoring. Sampling staff should be properly trained for each sampling method.

Monitoring is conducted to answer questions. As indicated above some typical questions are "What are the baseline conditions?" or "Is the landfill performing as designed?". Monitoring can be the first stage of a performance assessment. In the second stage, corrective actions are taken in response to any results that are above predefined performance criteria.

Performance monitoring is based on the idea that the operation of an engineered hazardous waste landfill facility is predictable and that performance criteria can be established prior to the start of operations. Some of these criteria may be related to meeting jurisdiction of authority requirements. Other monitoring is intended to assess whether the design is performing as expected (such as the monitoring of a leak detection system). Results outside the expected range should trigger further investigations and, if necessary, corrective measures long before any impact can be detected at the site boundary. Performance monitoring is also used to show the effectiveness of corrective actions.

Any monitoring should be performed at the correct location to get meaningful data, and quality assurance procedures should be used to provide confidence in the results.

Before an engineered hazardous waste landfill facility is established, a baseline environmental profile of the proposed facility site and the immediate surrounding area should be prepared. This baseline will serve as the reference point for later monitoring.

Health monitoring of all facility staff follow similar principals (baseline and routine screening) should be considered and adhere to jurisdiction of authority requirements.

The owner of an engineered hazardous waste landfill facility should run an environmental monitoring program for both the operational and post-closure periods. This program should monitor the physical movement of the facility, leachate leakage, groundwater chemistry, air emissions and general site conditions. Comprehensive historical records should be maintained of all data collected during the pre-operational, operational and post-closure stages.

Before an engineered hazardous waste landfill facility is constructed, environmental performance criteria should be established (based on the design specifications and jurisdiction of authority requirements). The actual performance should be monitored and compared with these criteria. Failure to meet these performance criteria should trigger additional investigations or a predetermined response.

6.1 Physical Movement

Engineered hazardous waste landfill facilities should be monitored for *subsidence* (i.e., settling) due to the collapse or consolidation of the landfilled wastes as described in Appendix I or compaction or erosion of the underlying native materials. If using a natural material cover, there may be a need to deal with cover erosion incidents.

Ongoing performance monitoring of the physical state of the facility should be performed to assess the long-term stability. Contingency plans should be triggered if the results do not meet predefined performance criteria.

6.2 Leachate

Monitoring of the leachate is important for checking the performance of the engineered systems and for determining the nature and interaction of the wastes in the engineered hazardous waste landfill facility. Leachate monitoring should be performed as described below and in Appendix I.

The amount of leachate and its composition should be monitored on a regular basis (using the appropriate jurisdiction of authority criteria and/or CCME guidelines). The data should be analyzed for trends. Contingency plans should be triggered if the results fail to meet predefined performance criteria, whether quantity, quality or detection thresholds. The leachate monitoring may also permit ongoing assessments of the compatibility of the leachate with the engineered components of the facility.

Performance monitoring should be conducted for the leachate collection system to compare the leachate pressure in the system with the design values. Contingency plans should be triggered if results fail to meet predefined performance criteria.

6.3 Leakage

The leak detection and recovery system (also called the secondary leachate collection system) is used to check the amount of leakage and the ongoing performance of the primary liner. When combined with monitoring of the volume of fluid collected by the primary leachate collection system, this also allows performance monitoring of the landfill cover. Monitoring should be performed according to the following guidelines and Appendix I.

The leak detection and recovery system should be regularly monitored for the presence of fluid. The recovered volumes from both the primary and secondary leachate collection systems should be monitored, along with the flow rates and chemical compositions of the leachate. Corrective actions should be taken whenever the leakage rates or specified contaminants exceed predefined performance criteria.

6.4 Groundwater

To show that an engineered hazardous waste landfill facility is performing as predicted and that the effects on the environment are acceptable, regular monitoring of the groundwater at strategic locations may be necessary. The monitoring should be based on a good understanding of the groundwater flow system in the area (using the hydrogeology studies and contaminant modelling performed during the site selection stage). This monitoring program may be developed using computer simulation of groundwater flow and contaminant transport. Since the construction of an engineered hazardous waste landfill facility can cause changes in groundwater levels and chemistry (even without any escape of leachate from the facility), the simulation should be refined over time based on the ongoing groundwater monitoring data. This refined understanding should be used for updated evaluations of facility performance.

The frequency of groundwater testing should be based on the predicted rate of contaminant transport along the pathway being monitored. In some instances, the testing required could be intensive and substantially more frequent than that discussed in Appendix I. The facility characteristics will dictate the actual performance monitoring requirements.

Further information on subsurface contaminant migration may be gathered by other means, such as the analysis of core samples of soil for the presence of contaminants.

Monitoring where contaminant detection is predicted to occur can confirm that the engineered hazardous waste landfill facility is functioning as predicted. This sample verification is as important as the non-detection of contaminants elsewhere in the environment. When no contamination is detected in a sample, it is assumed the facility is performing correctly. However, if the sample is collected from the wrong groundwater flow pathway then the negative result is meaningless and represents a “false negative”. Sampling should be sufficiently diverse to accurately monitor the facility’s performance.

Performance monitoring of groundwater should be conducted at strategic locations. Contingency plans should be triggered if the results exceed predefined performance criteria either in the type or the amount of contaminants.

6.5 Surface Water and Sediment

Regular monitoring of the surface water may be necessary to show that an engineered hazardous waste landfill facility is performing as designed and that the effects on the environment are acceptable. Discharges from on-site surface water control facilities should be monitored together with the potential effects on bodies of water that receive these discharges (see Appendix I).

Benthos and sediment monitoring in surface water features is an effective means of assessing impacts. Different benthic populations have varying levels of sensitivity to contaminant releases. Ongoing monitoring of these populations may detect the effects of a past contaminant release even if the release itself was not detected.

Performance monitoring of surface water and sediment should be conducted. Contingency plans should be triggered if the results exceed predefined performance criteria either in the type or the amount of contaminants.

6.6 Air Emissions and Landfill Gas

Air emission monitoring for engineered hazardous waste landfill facility operations consists of external “nuisance” sources (dust from operations such as earth moving, excavation, placing of wastes and placing of the cover) and landfill gas or vapour emissions (off-gassing and volatilization). Air emissions and landfill degassing should be sampled at various strategic locations around the site (see Appendix I).

The air quality monitoring program should be properly designed to contemporary requirements with the intent of providing objective data to address monitoring and point of impingement issues. Some aspects of the monitoring program may be designed to address jurisdiction of authority requirements.

Air quality sampling can consist of several different types of monitoring including

- discrete or “grab” samples,
- passive and active particulate monitoring and
- monitoring where air is actively or passively passed through a filter that is designed to detect specific contaminants (filter sampling).

The most informative sampling program may involve a longer accumulation or sustained sample collection as opposed to discrete or “grab” sampling in order to determine presence or absence of specific parameters.

If there is no weather station nearby that records wind speed and direction, such equipment should be installed at the engineered hazardous waste landfill facility site so that correlations between air quality measurements, wind direction and wind speed can be made.

Air emission performance monitoring should be conducted and should focus on the most likely emissions to be generated by the interned wastes. Toxic or explosive gases tend to be of the greatest concern and may consist of the most typical components such as H_2S and CH_4 or less common compounds such as HCN or H_2. The potential for gas generation exists over the contaminating lifespan of the hazardous wastes.

Landfill gas generation depends upon the ambient environment within the landfilled wastes (e.g., moisture content and temperature) and the waste composition. Waste composition will also influence the rate of gas generation but is dependent upon several of other aspects including the access availability to the contaminants. The principle mechanisms of toxic vapour generation at a hazardous waste landfill facility are waste volatilization, biological degradation and chemical reaction. Of these mechanisms, waste volatilization tends to be the most prevalent.

Recognizing the variability that can exist within the landfilled wastes; knowledge about the environmental conditions within the landfilled waste can greatly assist in determining the potential for gas production. Performance monitoring of the ambient environment may prove to be more insightful in assessing the potential for gas generation than the presence / absence sampling for the gases. Evaluation of leachate quality may also provide indications of whether gas production is anticipated.

Contingency plans should be triggered if the performance monitoring results exceed predefined performance criteria either in the type or the amount of contaminants detected or in the potential for vapour / gas generation.

6.7 General Inspection

The engineered hazardous waste landfill facility should be regularly inspected to confirm that it is being operated and maintained in accordance with approved conditions and good engineering practice. Special inspections should be performed following storms.

The owner of an engineered hazardous waste landfill facility should ensure that a general inspection program is implemented to address issues described in Appendix I.

Closure and Post-closure

7.1 Overview

"Closure" and *"post-closure"* care plans should be a requirement of an engineered hazardous waste landfill facility. An engineered hazardous waste landfill facility should commence final closure preparations at an appropriate time prior to the termination of its active filling lifespan. Closure procedures may also be applied to those portions of a large facility where filling operations are already completed.

7.2 Closure

Final closure refers to the point in time when a portion or the entire engineered hazardous waste landfill facility has been filled. It represents a transition period from active filling to a time when waste disposal has stopped and a final cover has been built. Specific procedures for closure are required to ensure that the long-term integrity and security of the facility is maintained. The protection of the environment and human health is of prime importance.

Closure care plans (see Appendix J) for an engineered hazardous waste landfill facility should be prepared as part of the initial planning and design phase for the overall facility. These plans should be updated if they are affected in any way by changes in facility design or operating procedures.

By including closure specifications in the original design, the engineered hazardous waste landfill facility development plan should be compatible with proper decommissioning and long-term care requirements after the facility has closed.

The owner of an engineered hazardous waste landfill facility should be required to close the facility in a manner that minimizes the need for further maintenance. In addition, any ongoing escape of hazardous contaminants to the groundwater, the surface water and the atmosphere must be controlled to the extent necessary to protect the environment and human health.

When closure of the landfill cell(s) is complete, all equipment and facilities used at the site (with the exception of long-term environmental control and monitoring facilities and equipment) should be decontaminated and/or disposed of in an appropriate manner.

7.3 Post-Closure

Post closure plans deal with period from the closing of the last active area of the facility until the point when the facility no longer poses any significant threats to the environment or human health.

Post-closure care plans (see Appendix J) for an engineered hazardous waste landfill facility should be prepared as part of the initial planning and design phase for the overall facility. These plans should be updated if they are affected in any way by changes in facility design or operating procedures.

Performance monitoring will continue for the contaminating lifespan of the engineered hazardous waste landfill facility or until the jurisdiction of authority is satisfied the facility no long poses any concern to the environment and human health.

The subsequent use of the engineered hazardous waste landfill facility site should be identified, the appropriate approvals from the jurisdiction of authority should be obtained at both the design and post-closure stage and the appropriate land use controls put in place to ensure that the designated use is not violated.

The approvals process is to ensure the environmental security of the waste. As a guide, long-term uses should be selected so that the security of the wastes deposited in the facility is not affected. This would exclude significant construction activities such as buildings, roads and pipelines. However, it may allow for less intensive land uses such as some forms of recreation. Access to the site should also be prohibited for an indefinite period.

The option chosen will depend on site-specific conditions, including the results of the ongoing monitoring program. If subsidence, erosion, gas venting or leachate generation becomes significant, then it may be desirable to seal off the site indefinitely until the situation is stabilized.

The monitoring systems should be maintained and operated on a regular basis during the post-closure period to check for possible problems. Particular attention should be paid to the groundwater monitoring system. In addition, periodic visual inspections of the site should be made to check the integrity of the landfill cover and the surface water drainage systems. These inspections would also ensure that the authorized use of the site is not being violated. Corrective measures should be taken as soon as potential problems are identified.

The post-closure care plan should provide a description of operational activities that will be conducted after final closure of the site (including their frequencies). As a minimum, these activities should include

- maintaining the function and integrity of the final cover,
- maintaining and operating the leachate and gas collection systems, along with any treatment systems still installed,
- maintaining the required site monitoring,
- protecting and maintaining survey benchmarks,
- controlling access to the site consistent with its approved post-closure use, and
- long-term contingency plan.

Financial Assurance

When an engineered hazardous waste landfill facility is approved, an appropriate financial assurance plan should be in place to ensure the safe continued operation of the facility over its contaminating lifespan. A financial assurance plan may allow phasing in of payments to correspond with different phases of the facility development. No waste should be received at an engineered hazardous waste landfill facility until sufficient financial assurance is provided to the jurisdiction of authority to meet the start-up and closure requirements outlined in that financial assurance plan.

If the owner fails to perform work or cover expenses requested by the jurisdiction of authority, this financial assurance may be used by the jurisdiction of authority to pay for any and all expenses related to any planned or unplanned activities of the facility operation.

The amount of financial assurance required will depend on the size and design of the facility, the type of hazardous wastes, and other factors specific to the site. Some jurisdictions of authority have specific requirements for the form and amount of financial assurance provided. A preset formula is used by some jurisdictions of authority to determine the amount of the financial assurance required.

This financial assurance is required to ensure that sufficient funds are available for all reasonably expected activities associated with the facility operation and closure.

The owner of an engineered hazardous waste landfill facility should provide financial assurance for the lifetime needs of the facility, including construction, operation, maintenance, replacement, closure and post-closure care, monitoring and reporting, and implementation of contingency measures.

The owner of an engineered hazardous waste landfill facility should ensure that any financial assurance used by the jurisdiction of authority is replaced within a reasonable period of time of its use, unless the jurisdiction of authority directs otherwise.

For closure and post-closure care, the financial assurance arrangements should meet the following requirements:

- the amount of financial assurance should be the present value at the estimated date of closure (in dollars current at that date) of an amount sufficient to cover the estimated closure and post-closure costs listed later in this section;
- the amount of financial assurance provided should be updated on a regular and set schedule;
- the financial assurance should remain in place until a written document is prepared showing (based on risk assessment) that the financial assurance is no longer required.

The closure and post-closure costs that may be paid by the financial assurance are for the following tasks:

- the planned closure of the largest area on the facility that will require final cover at any one time during the operation (including the costs of final cover and landscaping),
- care and maintenance of the final cover and landscaping for the contaminating life span of the facility, and
- all other reasonably expected post-closure care activities for the contaminating lifespan of the facility, including monitoring; analysis and reporting; design, construction, operation, maintenance and replacement of engineered facilities; and disposal of wastes from the facilities, as well as the implementation of contingency measures.

In the absence of any other information to the contrary, an estimated (yet conservative) contaminating lifespan for the leachate should be assigned from the date that the waste is last deposited at the facility. This estimate should be revised over time based on site-specific data.

The owner should provide supportable documentation to the jurisdiction of authority on the construction and operation costs of the engineered hazardous waste landfill facility.

Record Keeping

To ensure the continuity of post-closure care for the engineered hazardous waste landfill facility and to eliminate the potential for another party to unknowingly acquire this property, the site should be legally registered as a hazardous waste landfill on the appropriate deed or land title prior to commencing operation.

Regulated (or voluntary) reporting eliminates to the extent possible the potential for a purchaser to unknowingly acquire the engineered hazardous waste landfill facility property. The purpose of the reporting is to clearly establish the status of the engineered hazardous waste landfill facility. These Guidelines suggest several different documentation procedures involving different jurisdictions of authority to provide a level of reporting redundancy (e.g. registry on title and specific zoning restrictions). The specific requirements for the applicable jurisdiction of authority should be determined at the outset of the project.

9.1 Certificate of Closure

Within a reasonable period of time of completion of closure of the engineered hazardous waste landfill facility and within a reasonable period of time of completion of final closure, the owner should submit to the jurisdiction of authority certification that the facility was closed according to the specifications in the approved closure plan. Depending upon the jurisdiction of authority requirements, these specifications may include approval and notification conditions among other requirements.

The certification should be signed by the owner and by an independent qualified professional. Documentation supporting the certification of the independent qualified professional should be available to the jurisdiction of authority upon request until the owner is released from the financial assurance requirements for closure.

9.2 Survey Map or Plan

No later than the date of the submission of the certification of closure of the engineered hazardous waste landfill facility, an owner should submit to the local zoning authority (or the authority with jurisdiction over local land use) and to the jurisdiction of authority a survey map or plan of the facility. This survey map or plan should show the location and dimensions of landfill cells or other hazardous waste disposal units with respect to permanently surveyed benchmarks. This survey map or plan should be prepared and certified by a professional land surveyor. The survey map or plan filed with the local zoning authority (or the authority with jurisdiction over local land use) should contain a note, prominently displayed, which states the obligation of the owner or operator to restrict disturbance of the engineered hazardous waste landfill facility.

Land use restrictions for the completed engineered hazardous waste landfill facility site should be defined before closure and should be maintained over the contaminating lifespan. These restrictions should be registered on the land title.

9.3 Certification of Completion of Post-Closure Care

Within a reasonable period of time after the completion of the established post-closure care period for the engineered hazardous waste landfill facility, the owner should submit to the jurisdiction of authority certification that the post-closure care for the engineered hazardous waste landfill facility was performed according to the specifications in the approved post-closure plan.

The owner and an independent qualified professional should sign the certification. Documentation supporting the certification by the independent qualified professional should be available to the jurisdiction of authority upon request until the owner is released from the financial assurance requirements for post-closure care.

9.4 Preservation of Records

A central repository should be established containing "as-built" drawings of each landfill cell. The drawings should include the contents of each cell and the approximate location of each hazardous waste type within each cell. All relevant operating records of the engineered hazardous waste landfill facility should be maintained in this repository for an indefinite period, including all annual reports, monitoring data, public complaints and regulatory correspondences. This repository should also include the cumulative records of the monitoring programs during both the operational and post-closure phases of the site. All relevant site data and monitoring information should be electronically recorded and placed in the repository.

Once the engineered hazardous waste landfill facility is closed, all records should be placed in the custody of the jurisdiction of authority responsible for regulating the post-closure activities on the site. Financial compensation for this activity may be levied by some jurisdictions of authority at or before the time of transfer.

Closure Plan: a comprehensive site development plan that addresses all aspects of altering the facility operations from active filling to termination of filling operations and the subsequent site transformation to a passive land use of a secured engineered hazardous waste landfill facility. The plan includes all aspects of the engineered hazardous waste landfill facility closure program including, but not limited to: final cover construction and landscaping, operational decommissioning, modifications and mothballing, performance monitoring requirements, signage updating and similar logistical operation changes, security and access modifications, and associated administration changes and jurisdiction of authority documentation requirements.

Contaminating Lifespan: the length of time during which contents of the engineered hazardous waste landfill facility could still produce unacceptable levels of contaminants if a release occurred to the environment.

Criteria: the term used to identify the measured performance requirement or equivalent for these Guidelines.

Diffusion: is mixing of atoms or molecules that occurs because of random thermal motion and chemical concentration. Diffusion can transport contaminants in gases, liquids or solids, but diffusion rates vary widely depending on the material, the contaminant and the contaminant concentration.

Engineered hazardous waste landfill facility: is a term used to identify a facility that is designed to meet or exceed jurisdiction of authority requirements for the protection of the environment and human health. The design incorporates both the attributes of the natural environment and supplements them with the necessary engineered systems to achieve the required level of protection.

Engineered systems: manmade landfill components added to supplement the performance of the natural setting.

Exclusion area: represents any area around a receptor that is sufficiently sensitive as to warrant "exclusion" from impact. This could include (but is not limited to); human receptor sites such as homes, businesses, roadways or sensitive sites such as schools, nursing homes, hospitals; or environmental receptor sites such as fish spawning grounds, areas of natural or scientific interest, significant wetlands, migratory bird corridors, terrestrial migration corridors or habitat.

Final/Engineered Cover: an engineered system designed to isolate to the extent necessary the landfilled wastes from the environment. Traditional cover design deals with the placement of a manufactured hydraulic barrier consisting of an engineered layer of low-permeability clay and/or geotextile over the top of the landfill and tied into the liner system to fully encapsulate the landfill. Other systems may also be incorporated into the design, as required by the facility operations (i.e., landfill gas controls, monitoring equipment) and thus influence the final cover design.

Geosynthetic Clay Liners: factory-manufactured hydraulic barriers typically consisting of a thin (about 1 cm) layer of bentonite clay between two layers of geotextile, mechanically held together by needle-punching.

Guidelines: are the recommended requirements provided in this document for hazardous waste landfilling.

Hazardous waste: those materials having hazardous characteristics as defined in jurisdiction of authority legislation.

Hydraulic Conductivity (K): is a measure of the rate at which a liquid flows through a media (under specific conditions). Small values of *K* indicate a small flow rate.

Jurisdiction of authority: is the governmental authority having jurisdiction over the engineered hazardous waste landfill facility.

Landfill Development Plan: a comprehensive site development plan that includes all aspects of the engineered hazardous waste landfill facility layout including, but not limited to: landfill waste cells, buffer areas, storm water detention ponds, temporary cover storage areas, waste receiving and processing area(s); and all support infrastructure such as administrative and maintenance buildings, equipment storage complex, emergency facilities, etc.

Leachate: is the liquid formed when water percolates through waste and carries with it contaminants leached from that waste (and sometimes other fluid).

Leachate Management System: a system designed to monitor, collect and remove excess leachate from an engineered hazardous waste landfill facility.

Organic Chemicals: are any chemical compounds that contain carbon atoms, except for the very simplest ones such as carbon dioxide. Amongst the 60,000 organic compounds that can be analytically evaluated is a small subset of hazardous compounds (at specific concentration levels). These hazardous organic compounds are defined by jurisdiction of authority regulations.

Post Closure Care Plan: a comprehensive site plan that addresses all aspects of altering the site operations after the engineered hazardous waste landfill facility has completed closure operations. The plan includes all aspects of the on-going site operation including, but not limited to: leachate detection, collection and removal, storm water management, site access and security, site monitoring operations, landfill cover inspections and maintenance, contingency planning and implementation, record keeping and reporting.

Service Life: the length of time during which a system will work as intended.

Standards: this term is equated to legislated requirements by jurisdictions of authority

List of Acronyms

ASTM: American Society for Testing and Materials

CAEL: Canadian Association for Environmental Analytical laboratories

CANUTEC: Canadian Transport Emergency Centre

CCL: compacted clay liner

CCME: Canadian Council of Ministers of the Environment

CQA: construction quality assurance

$D_{\#\#\%}$: distribution parameter

EMS: environmental management system

GIS: Geographical Information System

GCL: geosynthetic clay liner

GM: geomembrane

HDPE: high density polyethylene

LDS: leak detection system

QA/QC: quality assurance / quality control

WHMIS: Workplace Hazardous Materials Information System

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Site Selection

These Guidelines are a model set of technical requirements. They come into effect only if adopted, in whole or in part, by a jurisdiction of authority. Even where these Guidelines have been either completely or partially adopted by a jurisdiction of authority, the application of the guidelines are subject to any restrictions or conditions that are in place or could be added by that jurisdiction of authority. Readers of these Guidelines should check with the jurisdiction of authority to see whether any of these Guidelines currently apply. The specific requirements of the applicable jurisdiction of authority should be incorporated into the design and operation of the engineered hazardous waste landfill facility.

The engineered hazardous waste landfill facility needs to be sited to ensure that viable contingency measures can be implemented, if required. A viable contingency measure is one where there is sufficient time, or alternatively sufficient separation distance, between the engineered hazardous waste landfill facility and the exclusion area for the release to be detected and measures implemented to prevent an adverse impact. The required separation distance between the engineered hazardous waste landfill facility and an exclusion area should be based on the contaminant travel time along the preferred pathway.

The site location should be selected to minimize the possibility of unacceptable outcomes such as

- surface water contamination,
- contamination in parks and wildlife areas,
- accidental release of contaminants,
- excessive leachate formation, or
- contamination in populated or public areas.

A.1 Prevention of Surface Water Contamination

An engineered hazardous waste landfill facility should be isolated from all surface water features, so that the contaminant travel time is based primarily on groundwater migration.

The travel time of contaminated groundwater at the engineered hazardous waste landfill facility to any surface water feature should be reasonably long. Undesirable locations include (but are not limited to)

a) areas that may be subject to flooding;
b) areas that may be subject to tsunamis;
c) areas that may be subject to tidal flooding; and
d) areas within a defined portion of a dynamic beach.

A.2 Prevention of Contamination in Parks and Wildlife Areas

There should be a sufficiently long travel time for contaminants from an engineered hazardous waste landfill facility to the nearest boundary of any of the following areas:

a) national, provincial, territorial, regional or municipal parks;

b) wildlife management or protection areas designated by the jurisdictions of authority;
c) wildlife area or wildlife sanctuaries designated by the jurisdictions of authority and/or pursuant to the Canada Wildlife Act;
d) ecological reserves, areas of natural or scientific interest or environmentally sensitive areas designated by the jurisdictions of authority; and
e) bird sanctuaries designated by the jurisdictions of authority and/or pursuant to the Migratory Bird Convention Act (Canada).

A.3 Prevention of Accidental Release of Contaminants

There should be a sufficiently long travel time for contaminants from an engineered hazardous waste landfill facility to any unstable land form or any groundwater resource. Undesirable locations include (but are not limited to)

a) areas near lands subject to slope failure;
b) areas near active erosional features such as bluffs, banks, dunes and escarpments;
c) areas near active geotechnical features such as unmanaged permafrost or sink holes;
d) areas near a fault that has had significant geotechnical activity;
e) areas near geological features possessing relatively high groundwater flow characteristics; and
f) vulnerable source water areas including, but not limited to, critical surface water and groundwater recharge areas, surface water intakes, highly vulnerable aquifers, wellhead protection, areas or zones, and groundwater and surface water sources identified for future water supply.

A.4 Prevention of Excessive Leachate Formation

The expected precipitation at the engineered hazardous waste landfill facility site should not be excessive. Undesirable locations include (but are not limited to)

a) areas where the average precipitation in any month is greater than the combined capacity of evapotranspiration and groundwater storage (unless the effects of precipitation are controlled during wet months so that the landfill performance is equivalent to that achieved under acceptable levels of precipitation); and
b) areas where the average annual precipitation is greater than the average annual evapotranspiration through the cover of the closed facility.

A.5 Prevention of Contamination in Populated or Public Areas

The site should not be near designated populated or public areas. The separation between an engineered hazardous waste landfill facility and populated areas should consider atmospheric, surface and groundwater times of travel. Zoning may be used to establish and maintain the required separation. Jurisdictions of authority may have specific numerical criteria for separation distances and should be consulted regarding their specific requirements. Undesirable locations include (but are not limited to)

a) areas that are not a reasonable distance from a dwelling in case of a catastrophic atmospheric release;
b) areas that are not a reasonable distance from a public road that facilitates roadside drainage to surface water courses; and
c) distinctive urban settings such as a school.

Site Evaluation and Facility Design Assessment

These Guidelines are a model set of technical requirements. They come into effect only if adopted, in whole or in part, by a jurisdiction of authority. Even where these Guidelines have been either completely or partially adopted by a jurisdiction of authority, the application of the guidelines are subject to any restrictions or conditions that are in place or could be added by that jurisdiction of authority. Readers of these Guidelines should check with the jurisdiction of authority to see whether any of these Guidelines currently apply. The specific requirements of the applicable jurisdiction of authority should be incorporated into the design and operation of the engineered hazardous waste landfill facility.

An engineered hazardous waste landfill facility needs to be sufficiently isolated from all nearby sensitive environmental features so that viable contingency measures can be implemented. A viable contingency measure is one where there is sufficient time (or alternatively sufficient separation distance) between the engineered hazardous waste landfill facility and the receptor such that the release can be detected and preventative measures can be implemented before an adverse impact occurs.

All site evaluations and facility design assessments for engineered hazardous waste landfill facilities require the collection and evaluation of baseline data. Appendix B provides an insight into the level of effort necessary to establish a sufficient information database. It also describes the types of informational requests that may be made by jurisdictions of authority as part of the evaluative process. The requirements and specifications are divided into four general areas:

- facility design,
- buffer area,
- groundwater, and
- surface water.

B.1 Facility Design Specifications

An engineered hazardous waste landfill facility should not be established unless documentation has been prepared that contains complete descriptions of the following elements:

- the proposed site setting,
- the engineered systems,
- the potential environmental impacts,
- the proposed measures to mitigate any environmental impacts of the facility, and
- the main characteristics of the facility operation.

Such a document should also be considered for an expansion of an engineered hazardous waste landfill facility including, but not limited to: an alteration, enlargement or extension of area or volume; or approving / permitting additional hazardous waste types / classes for disposal in an existing facility.

B.1.1 The proposed site

The documentation should include all of the following:

a) a legal survey of the site;

b) an up-to-date plan and description of the existing site setting and the surrounding area within a reasonable distance indicating all
   - land holdings, property boundaries, rights-of-way and other easements;
   - buildings, roads and utility corridors;
   - land contours, surface water drainage and water bodies;
   - forested areas, land uses and land use designations; and
   - any other relevant property conditions not covered in this list including those requirements of the jurisdiction of authority.

c) detailed plans, specifications and descriptions for the proposed landforms of the facility, including
   - a plan and description of the waste fill area, base contours for waste disposal, base contours for any leachate collection system, top contours for waste disposal, and top contours with the final cover in place (noting how the closed site will fit into the surrounding landscape, or the intended final end use); and
   - the total volume of waste disposal;

d) a geotechnical assessment of the suitability of the facility site that considers
   - the load bearing capacity, the potential for differential settlement and basal heave, and the slope stability (during construction, operation and post-closure for all of the above); and
   - the consequent stability of any liner, leachate collection and cover systems;

e) an environmental assessment of the suitability of the facility site that considers the facility design, performance monitoring and contingency plans; and

f) a meteorological assessment of the suitability of the facility site that considers the prevailing wind conditions (including the effects of the local environment), the norms and extremes of precipitation and temperature, and the evaporation potential of the site and surrounding area.

B.1.2 Engineered systems

The documentation should include detailed plans, specifications and descriptions for all the engineered systems, together with the construction and quality assurance / quality control procedures for materials and installation. The documentation should include these details for

a) any liner system;

b) any leachate collection, leak detection, or leachate treatment and disposal system, as well as an assessment of the expected quality and quantity of leachate;

c) the final cover system;

d) any system for monitoring or controlling landfill gas migration, as well as an assessment of the potential for subsurface migration of landfill gas at the facility;

e) any system for venting or collecting landfill gas (for subsequent burning or other use), as well as
   - an estimate of the service life of every engineered system associated with the landfill gases and leachate and
   - an assessment of the effects of interaction with the landfill gases on the service life of any liners, leachate collection and leak detection systems;

f) all systems for collecting, directing and discharging surface water, including details of any sediment control or other special features; and

g) all performance monitoring facilities for leachate, groundwater, surface water and (where appropriate) landfill gas.

B.1.3 Potential environmental impacts

The documentation should include assessments of the potential effects of the engineered hazardous waste landfill facility on all of the following:

a) the local surface water features;
b) the benthic (bottom-dwelling aquatic) flora and fauna of the local surface water features;
c) the ecology of the site and surrounding area;
d) any archaeological features on the site and in the surrounding area;
e) the noise level of the surrounding area (potentially increased by operations at the site or by local trucking related to operations), as well as evaluations of any proposed noise control measures; and
f) any visual assets that may be seen from nearby properties (potentially affected by views of the site or of site operations).

B.1.4 Documentation of mitigation measures

The documentation should include detailed plans, specifications and descriptions of all of the following mitigation measures and strategies:

a) the buffer area and ancillary facilities such as any screening, landscaping, fencing, weigh scales, buildings, structures, access roads, internal roads, holding areas for cover material, holding areas for rejected waste or materials for treatment or recycling, and other holding areas;
b) the contaminant attenuation zone (if one is necessary);
c) the contingency plans to control and dispose of leachate or landfill gas migrating in the subsurface (if either is produced in a quantity greater than expected or with a quality worse than expected), including sufficient detail to demonstrate the feasibility of the plans;
d) any facilities intended to control or change the contaminating life span of the engineered hazardous waste landfill facility;
e) the daily cover, including
   - a description of the source, nature and quality of daily cover (including materials not normally used);
   - a discussion of its benefits and limitations; and
   - a description of its application rates and application procedures (including the frequency and timing of application if applied at other than the end of each working day);
f) the final cover, including
   - a description of its nature, quality and quantity;
   - construction details and quality assurance / quality control (QA/QC) procedures for the materials; and
   - the limitations of the materials;
g) the conceptual site closure plan, including details of
   - the removal of existing facilities to facilitate closure, post-closure and end use of the site;
   - the appearance of the site after closure (after landscaping, revegetation, and the construction of new facilities); and
   - the proposed end use of the site.

B.1.5 Main operational characteristics of the facility

The documentation should include all of the following:

a) an estimate of the contaminating life span of the engineered hazardous waste landfill facility due to the subsurface migration of landfill gas, as well as an estimate of the service life of any engineering facilities associated with controlling this problem;
b) an estimate of the contaminating life span of the facility due to migration of the leachate, as well as an estimate of the service life of all engineered facilities associated with controlling this problem (including an assessment of the effects of the leachate on the service life of any liners, leachate collection and leak detection systems);
c) a summary of the main characteristics of the landfilling area of the facility, including
   - the maximum daily quantity of waste that will be accepted for disposal,
   - the estimated annual average quantity of waste that will be accepted for disposal,
   - the area of the landfilling site,
   - the area of the waste fill portion of the site,
   - the total waste disposal volume,
   - the estimated waste disposal capacity in tonnes,
   - a list of any subcategories of hazardous waste that are not expected to be received or that will not be accepted for disposal, and
   - the estimated date of site closure.

B.2 Buffer Area Specifications

The buffer area or buffer zone is a green space that is located between the waste fill area and the site boundaries. The buffer area allows for contaminant attenuation and provides space around the perimeter of the waste area for various monitoring, maintenance and environmental control activities.

The waste fill area of an engineered hazardous waste landfill facility should be completely surrounded by a buffer area that is established and managed according to the following guidelines:

a) At every point, the buffer area should extend beyond the distance calculated for a reasonable contaminant travel time in the groundwater or beyond a reasonable width.
b) The buffer area should be sufficient to ensure that the landfilling operation does not have any unacceptable impacts outside the site (such as surface runoff, the spread of litter or vermin, the escape of leachate, or the subsurface migration of landfill gas).
c) The buffer area should accommodate all performance monitoring sites and still be able to implement contingency measures inside the property boundary if necessary.
d) The buffer area should either be
   - not planted with any vegetative screening that would increase the rate of contaminant travel in the buffer area, or
   - widened to allow for an increase in contaminant travel due to plantings.
e) Encroachment onto the buffer area should be avoided for a minimum period of time (such as 25 years) following the completion of post-closure care.

Jurisdictions of authority may have specific numerical criteria regarding buffer areas and should be consulted regarding their specific requirements.

B.3 Hydrogeological/Groundwater Assessment

An assessment of the hydrogeologic setting of an engineered hazardous waste landfill facility is necessary to ensure that the site has the required minimum characteristics for consideration, that it can be properly designed and constructed, and that it can be effectively monitored during the facility's contaminating life span.

An engineered hazardous waste landfill facility should not be established until after the preparation of a favourable hydrogeological assessment that provides

- a report on the groundwater characteristics of the regional area,
- a report on the groundwater characteristics of the local area,
- an objective interpretation of the results of the groundwater investigations, and
- an assessment of the suitability of the site based on the groundwater investigations.

Such a hydrogeological assessment should also be considered for an expansion of an engineered hazardous waste landfill facility including, but not limited to: an alteration, enlargement or extension of area or volume; or approving / permitting additional hazardous waste types / classes for disposal in an existing facility.

B.3.1 Groundwater in the regional area

The documentation should contain a general description of the geologic, geochemical and hydrogeologic conditions of the region within a reasonable distance, including (but not limited to)

a) a description of the stratigraphy (i.e., the soil and rock layers) of the region,
b) the location of hydrogeologic boundaries,
c) a description of groundwater quality and quantity,
d) a description of groundwater movements,
e) identification of the groundwater recharge and discharge zones, and
f) a description of groundwater resources and the uses made of these resources.

The documentation should also contain an objective conceptual model of the geologic, hydrogeologic and geochemical conditions of the site and the surrounding area.

B.3.2 Groundwater in the local area

The documentation should contain a detailed description of the geologic, geochemical and hydrogeologic conditions both at the site and in the surrounding local areas within a reasonable distance. This distance may be either a defined radius from the site or a distance that a "*conservative contaminant*" can travel in the groundwater system within a reasonable period of time.

Site investigations should be conducted hydraulically upstream and downstream of the potential waste fill area, as well as at other locations as necessary (including areas adjacent to the facility site). The investigations should be conducted either to the maximum depth that could be affected over the contaminating lifetime of the engineered hazardous waste landfill facility or to a reasonable depth. They should also be conducted in a manner sufficient to

a) provide the soil samples required to adequately characterize the soil units underlying the site for their thickness and type, and their physical and chemical properties,
b) permit the geological and geophysical logging of boreholes if necessary,

c) permit the tracer testing of "*hydrostratigraphic units*" if necessary,
d) permit the installation of groundwater monitoring facilities if necessary,
e) permit other tests (e.g., geotechnical or geochemical) of soil and borehole properties if necessary, and
f) permit the testing of bedrock properties if necessary.

None of these investigations should compromise the integrity of the engineered hazardous waste landfill facility site or create conduits that could act as short-circuits for contaminant migration over the lifetime of the site. All investigation boreholes should be properly constructed and properly abandoned if not to be used. The proper documentation of their construction and decommissioning should be kept and registered with the jurisdiction of authority, if required.

The documentation of the local area groundwater characteristics should be based on a detailed investigation that establishes the soil, rock and groundwater conditions of the engineered hazardous waste landfill facility site, including (but not limited to)

a) an investigation of the soil and rock properties, chemistry and quality (using drilling, coring, drive-points, test-pitting, trenching and other means of soil excavation and sample extraction to obtain representative samples);
b) collection of groundwater samples or the measurement of groundwater levels or hydraulic pressures representative of the hydrostratigraphic units at the site (following the installation of groundwater monitoring instruments in boreholes);
c) a thorough survey of all operational and abandoned wells (including water wells) within a reasonable distance of the site or within the distance for a reasonable contaminant travel time;
d) an analysis of groundwater samples from groundwater monitoring instruments and selected local well sites for the parameters listed in the CCME Canadian Environmental Quality Guidelines or in accordance with applicable jurisdiction of authority requirements, and
e) pumping tests, slug tests and other hydraulic testing procedures (as necessary) to measure the in-situ permeability of geologic materials at the site.

To ensure the validity of the data collected, the documentation should describe

a) the development, operation and maintenance (e.g., purging) of groundwater monitoring instruments as necessary to ensure that the data and the samples collected from the groundwater monitors are representative of hydrogeologic conditions at the site;
b) the collection of a sufficient number of representative measurements of groundwater level or hydraulic pressure (in groundwater monitoring facilities and selected local well sites) to confirm that
    - the groundwater monitor or well is functioning properly,
    - the groundwater monitor is isolated within one hydrogeologic horizon and is not causing any degree of cross-flow or cross-contamination,
    - a static water level has been attained,
    - any differences (lateral or vertical) in water level or hydraulic pressure at the site may be detected, and
    - any seasonal variations (or other trends) in groundwater levels and groundwater flow may be detected;

c) the collection of a sufficient number of groundwater samples (from groundwater monitoring instruments and selected local well sites) over a sufficient period of time to confirm that
    - the groundwater monitor or well is functioning properly,
    - the groundwater monitor is isolated within one hydrogeologic horizon and is not causing any degree of cross-flow or cross-contamination,
    - the seasonal variability (or other trends) of groundwater chemistry or quality may be detected,
    - the horizontal and vertical spatial variability of groundwater chemistry or quality may be detected, and
    - the isotopic profile of hydrostratigraphic units may be measured to confirm long-term groundwater flow velocities.

B.3.3 Interpretation of the groundwater investigations

The documentation should contain an objective interpretation of the results of the detailed groundwater investigations for the engineered hazardous waste landfill facility site together with the relevant plans, specifications and descriptions for the site (under pre-construction conditions, during facility construction and operation, and following facility closure). All of the following should be included:

a) a contour plan (at a 1-metre contour interval) of the ground surface, showing any surface watercourses and bodies of water;

b) a contour plan of the water table, showing the expected directions of groundwater movements (including an objective evaluation of the uncertainty in the interpretation);

c) the piezometric contour plans for each aquifer, showing the expected directions of groundwater movement (including an objective evaluation of the uncertainty in the interpretation);

d) a description of all aquifers and their interconnections, with estimates of groundwater flows (including an objective evaluation of the uncertainty in the interpretation);

e) a description of the background quality of the groundwater in each aquifer system, as well as the existing and potential uses of the groundwater from each aquifer system;

f) the site plans and the cross-sections of the hydrogeologic conditions of the site (as well as an objective evaluation of the uncertainty in the interpretation);

g) the site plans and the cross-sections of the hydrogeochemical conditions of the site (as well as an objective evaluation of the uncertainty in the interpretation);

h) identification of any unstable soils or unstable bedrock;

i) a description of the flow velocities and the volumetric flow rates in the aquifers (as well as an objective evaluation of the uncertainty in the interpretation);

j) a time-of-travel evaluation for the conservative and reactive contaminants to be buried in the facility;

k) a water balance analysis that considers precipitation, surface water drainage, infiltration, groundwater flow, exfiltration and evapotranspiration;

l) the potential flow paths and contaminant attenuation capabilities for leachate escaping the waste fill area (in either planned or unplanned quantities);

m) an objective assessment of the ability of the proposed contingency system to mitigate the effects of groundwater leachate flow along identified pathways; and

n) a reasonable estimate of the maximum groundwater impact expected from the facility and the time at which it is expected to occur, calculated using a numerical simulation of the migration of key contaminants (including considerations of the uncertainties of hydrogeologic parameters and of the service lives of the engineered components of the barrier system, if any).

B.3.4 Suitability of the site based on groundwater investigations

The documentation should conclude with an assessment of the suitability of the site for hazardous waste land disposal purposes based on the groundwater investigations. This assessment should consider

- the regional and site-specific geologic, geochemical and hydrogeologic conditions;
- the design of the engineered hazardous waste landfill facility;
- the requirements for monitoring the potential effects of the facility on the groundwater; and
- the contingency plans for the control of leachate and landfill gas.

B.4 Surface Water Assessment

The suitability, design and monitoring requirements for an engineered hazardous waste landfill facility will be determined in part by an objective assessment of its potential impacts on surface water features (including those on the site, near the site and receiving a discharge from the site).

Jurisdictions of authority may have specific numerical criteria for such an assessment and should be consulted regarding their requirements.

An engineered hazardous waste landfill facility should not be established unless suitable documentation on surface water conditions and protection measures has been prepared. This documentation should include

- a report on the surface water setting at a regional watershed and local scale,
- a report on the flow characteristics and habitat suitability of the surface water features,
- an objective interpretation of the projected effects of the engineered hazardous waste landfill facility on the surface water, and
- an assessment of the suitability of the site based on the surface water characteristics.

Such a document should also be considered for an expansion of an engineered hazardous waste landfill facility including, but not limited to: an alteration, enlargement or extension of area or volume; or approving / permitting additional hazardous waste types / classes for disposal in an existing facility.

B.4.1 Regional and local surface water watershed

The documentation of the watershed information should include

a) a general description of the surface water features of the area on a regional and local watershed scale, including (but not limited to) flood plains, natural watercourses, drainage paths and boundaries, municipal drains, stream flows, surface water quality, and sources of water supply; and

b) a detailed description of the surface water features occurring within a reasonable distance of the waste fill area, including descriptions of all contributing and receiving surface water features that are sufficiently large to allow the practical assessment of potential effects.

B.4.2 Surface water flow and habitat characteristics

The documentation should present detailed investigations into the quantity, the quality and the habitat conditions of the surface water features associated with the engineered hazardous waste landfill facility site. These should include any surface water features on the site, any that are flowing through the site, and any that will receive a surface water discharge from the site. The assessment should evaluate a sufficient portion of the surface water feature (i.e., both upstream and downstream) such that it can be adequately characterized.

The investigations should include (but are not limited to)

a) quantity investigations to assess current stream flow conditions, including
   - low-flow characteristics,
   - stream-groundwater interactions (i.e., discharge / recharge conditions), and
   - seasonal flow variations (using either actual measurements over time, comparisons with or extrapolations from historical databases, or numerical evaluations from established computer simulations);

b) investigations to assess the current water quality and the seasonal variations in quality, such as
   - semi-annual (or more frequent) monitoring to look for any compounds known to be commonly used in industry or agriculture within the watershed of the proposed site (to assess whether any of these should be included in the surface water monitoring program),
   - semi-annual (or more frequent) monitoring for the water quality parameters listed under the Community Water Guidelines in the Canadian Environmental Quality Guidelines of the CCME (or in accordance with applicable jurisdiction of authority requirements),
   - monitoring on six other occasions (within each year) for the parameters listed in under the Community Water Guidelines in the Canadian Environmental Quality Guidelines of the CCME, or in accordance with applicable jurisdiction of authority requirements (this extra sampling is intended to evaluate the geochemical differences that may occur due to spring melt, large storm events, or other changes in baseline flow conditions);

c) a baseline benthic (bottom-dwelling flora and fauna) community inventory that covers factors such as location, sensitivity or use of the surface water feature; and

d) a baseline streambed sediment quality sampling program to look for any compounds known to be commonly used in industry or agriculture within the watershed of the proposed site (and to assess whether any of these should be included in the surface water monitoring program).

B.4.3 Interpretation of the surface water investigations

The documentation should include an interpretation of the results of the detailed investigation of the effects on relevant surface water features. These should include features that are either on the engineered hazardous waste landfill facility site, that flow through the site, or that are to receive a direct discharge from the site. This interpretation should include

a) plans showing all existing surface water features,
b) descriptions of the current surface water quality as well as the existing and proposed surface water uses,
c) a summary of sampling results,
d) a review of monitoring data available from other sources (either jurisdictions of authority or private sector) for areas both upstream and downstream of the site,
e) a detailed hydrologic assessment of the site effects on relevant surface water features, including (but not limited to)
   - changes in the frequency, magnitude and duration of stream flow at key locations (entering, passing through and leaving the site),
   - changes in surface-water flood levels within relevant watercourses,
   - changes in the average annual water budgets (including changes in evapotranspiration, infiltration, surface runoff and groundwater recharge/discharge volumes) expressed over the site area and the contributing drainage area, and
   - changes in temperature and average annual sediment loading to receiving watercourses (at key locations discharging from the site);
f) the potential leachate flow paths and locations of any intersections with surface water features within a reasonable distance of the waste fill area; and
g) an assessment of the viability of the proposed contingency system to mitigate the effects of identified leachate flow paths on surface water features.

B.4.4 Suitability of the site based on surface water investigations

The documentation should conclude with an assessment of the suitability of the engineered hazardous waste landfill facility site for waste disposal purposes based on the investigations into the surface water conditions. This assessment should consider

- the area in which the facility site is located,
- the on-site and receiving surface water features,
- the design of the facility, and
- the contingency plan for the control of leachate.

Stormwater Management

These Guidelines are a model set of technical requirements. They come into effect only if adopted, in whole or in part, by a jurisdiction of authority. Even where these Guidelines have been either completely or partially adopted by a jurisdiction of authority, the application of the guidelines are subject to any restrictions or conditions that are in place or could be added by that jurisdiction of authority. Readers of these Guidelines should check with the jurisdiction of authority to see whether any of these Guidelines currently apply. The specific requirements of the applicable jurisdiction of authority should be incorporated into the design and operation of the engineered hazardous waste landfill facility.

Proper stormwater management is a key consideration in the design and construction of an engineered hazardous waste landfill facility. The objectives of the stormwater control system for an engineered hazardous waste landfill facility are to

- control runoff discharging from the facility site;
- divert or control stormwater coming onto the facility site; and
- control erosion, sedimentation and flooding.

An engineered hazardous waste landfill facility should not be established unless documentation has been prepared that contains plans, specifications and descriptions for the control, treatment and discharge of surface water. This documentation should cover stormwater concerns during all phases of construction, site operation and post-closure. It should also include descriptions of the operation, inspection and maintenance requirements for any stormwater control, treatment and discharge systems, including erosion and sediment control systems.

In addition, performance monitoring procedures for surface water control should be established as described in Section I.3 of Appendix I.

The documentation should clearly differentiate between the following types of stormwater flows:

- *run-on stormwater,* which is off-site surface water that has been separated from facility operations by means of diversions, berms, interceptor channels, and related structures;
- *non-contaminated stormwater,* which is on-site runoff originating from non-operating areas (i.e., it does not contact landfilled waste, leachate or wastewater); and
- *potentially contaminated stormwater,* which is on-site runoff originating from landfilling areas, materials and waste storage areas, or on-site stormwater collection areas.

Such a document should also be considered for an expansion of an engineered hazardous waste landfill facility including, but not limited to: an alteration, enlargement or extension of area or volume; or approving / permitting additional hazardous waste types / classes for disposal in an existing facility.

Jurisdictions of authority may have specific numerical criteria related to stormwater management, such as a reasonably expected storm, and jurisdiction of authority should be consulted regarding their requirements.

C.1 Control of Runoff

The plans, specifications, and descriptions for the control of runoff from the site should include

a) a site drainage plan showing the drainage of surface water before the engineered hazardous waste landfill facility is established, during operation, and following closure;
b) the design features, control systems and operational procedures to isolate, contain, monitor, convey, control and treat the stormwater (on and off the facility) prior to its discharge to the receiving watercourse(s);
c) measures to ensure that the concentration of any contaminant in the surface water being discharged from the facility site is in accordance with applicable jurisdiction of authority requirements; and
d) evidence that the hydrologic cycle and the background levels for dissolved oxygen, turbidity and temperature of any on-site, adjacent or receiving surface water features are not adversely affected by the construction and operation of the facility.

C.2 Control of Stormwater

Stormwater control systems should be designed and located in accordance with the following guidelines:

a) The design of stormwater control systems should be based on accepted methodologies, calculations and analytical tools including (where appropriate) hydrologic, hydraulic and water quality modeling.
b) The design of external diversion channels, ditches and conveyance structures should be sized to accommodate the peak flow generated by the regional storm event (i.e., the largest storm on record).
c) The design of all lined internal drainage channels, ditches, storm sewers and conveyance structures should be designed
   - to accommodate the peak flow generated by a reasonably expected storm, and
   - to ensure that any upset condition (i.e., overflow) flows back into the facility.
d) Continuous overland flow routes, ditches and conveyance structures for both clean and non-contaminated stormwater should be provided and sized to convey the peak flow generated by “the regional storm event.”
e) Any stormwater control systems built for the enhancement of water quality (such as lined sedimentation ponds) should be designed
   - to treat and store temporarily the runoff volume generated from a reasonably expected storm, and
   - to ensure that any “upset condition” flows back into the facility.
f) Lined overflow control systems should be designed to convey safely any stormwater flows in excess of those from any level of storm specified in the design.
g) Any stormwater control systems built for quantity control (i.e., peak-flow reduction) of clean and non-contaminated stormwater should be designed to store temporarily the relevant runoff volume from all storm events up to a 24-hour period for the regional storm event.

h) After storms have passed, the collection and holding systems associated with on-site or off-site control systems should be quickly emptied or otherwise managed to maintain the design capacity of the system.

C.3 Control of Erosion and Sediment

Any temporary or permanent erosion and sediment control systems or measures (including those for stormwater control, systems construction or facility operation) should be designed and located in accordance with the following guidelines:

a) Any lined stormwater management systems used for enhancing the quality of contaminated stormwater should be designed
   - to treat and store temporarily the relevant runoff volume generated from a reasonably expected storm, and
   - to ensure that any "upset condition" flows back into the facility.

b) Lined overflow control systems should be designed to safely convey any stormwater flows in excess of those from any level of storm specified in the design.

c) Any stormwater management systems used for controlling the quality of clean and non-contaminated stormwater should be designed
   - to store temporarily the relevant runoff volume generated from all storm events up to a 24-hour period for the "regional storm event", and
   - to maintain control limits at or below the peak flows of the existing condition (i.e., pre-landfill), such that there is no appreciable change in the potential for flooding or erosion in the watercourses receiving surface water discharges from the landfilling area.

d) After storms have passed, the collection and holding systems associated with on-site or off-site control systems should be quickly emptied or otherwise managed to maintain the design capacity of the system.

Landfill Gas Control

These Guidelines are a model set of technical requirements. They come into effect only if adopted, in whole or in part, by a jurisdiction of authority. Even where these Guidelines have been either completely or partially adopted by a jurisdiction of authority, the application of the guidelines are subject to any restrictions or conditions that are in place or could be added by that jurisdiction of authority. Readers of these Guidelines should check with the jurisdiction of authority to see whether any of these Guidelines currently apply. The specific requirements of the applicable jurisdiction of authority should be incorporated into the design and operation of the engineered hazardous waste landfill facility.

Biodegradation of some waste materials releases gases such as methane and carbon dioxide to the subsurface. Incompatible wastes or leachates can also form gases as products of chemical reactions. Two types of release are possible for landfill gases:

- subsurface migration, and
- release to the atmosphere.

D.1 Subsurface Migration of Landfill Gases

The release of gases from an engineered hazardous waste landfill facility is generally low, but an assessment should still be completed of the potential for the generation and release of these gases to the subsurface. An engineered hazardous waste landfill facility should not be established unless documentation has been prepared that contains plans, specifications and descriptions for the monitoring and control of subsurface gases. Such a document should also be considered for an expansion of an engineered hazardous waste landfill facility including, but not limited to: an alteration, enlargement or extension of area or volume; or approving / permitting additional hazardous waste types / classes for disposal in an existing facility.

D.1.1 Assessment and control of subsurface landfill gas migration

a) The documentation should include an assessment of the potential for the migration of landfill gas in the subsurface, including
   - background concentrations of volatile compounds and any existing potential sources of volatile compounds other than the waste,
   - the potential for generation of volatile compounds by the waste,
   - the potential for migration of landfill gases below the surface of the land to off-site properties or into buildings (or other enclosed structures) located on or off the site,
   - the potential for migration of landfill gases into and along any buried utility or service lines, and
   - the generation of volatile compounds from interactions between the wastes and the leachate.

b) The documentation should include plans, specifications and descriptions for the monitoring, control, collection, use or discharge of landfill gases at the site if any of these actions are necessary (as determined by the assessment above).

D.1.2 Health and safety considerations

a) The design of the engineered hazardous waste landfill facility and any plans, specifications and descriptions for the control of landfill gases should include the following conditions:
   - Below the surface of the land at an appropriate designated point (such as the property boundary of the site), the concentration of volatile compounds should be less than jurisdiction of authority requirements.
   - Inside any on-site building or enclosed structure (if the building or structure is accessible to any personnel or if it contains electrical equipment or other potential sources of ignition), the concentration of volatile compounds should be below the required occupational health and safety exposure standards. This condition also applies in the area immediately outside the foundation or basement floor of the building or structure.
   - The point above does not apply in locations where specific occupational health and safety measures are already in place to reduce the risk of asphyxiation or explosion (such as in an engineered system for leachate collection, storage or treatment or in an engineered system for landfill gas collection or treatment).

b) If volatile compounds are expected to be generated at the engineered hazardous waste landfill facility, the documentation should include the following requirements for any buildings or enclosed structures that may be affected:
   - For any occupied building on the site, monitoring devices (with detection alarms) for volatile compounds should be provided. For other buildings or enclosed structures that are accessible by any person, strict protocols for entering confined spaces should be enforced.
   - For any building or enclosed structure located on the engineered hazardous waste landfill facility site that contains electrical equipment or any potential source of ignition, a general description should be provided of the safety precautions to be taken in the presence of volatile compounds.

D.1.3 Monitoring and contingency planning

a) If migration of the landfill gas is to be monitored, the documentation should include (at a minimum)
   - the design of the monitoring devices,
   - the monitoring locations,
   - the frequency and period of monitoring, and
   - the parameters to be analyzed, including the concentration of methane gas and the gas pressure within the monitoring devices.

b) The documentation should include a contingency plan to control landfill gas migration below the land surface. This plan would be implemented if volatile compounds migrate from the waste fill area at concentrations in excess of those specified in Section D.1.2(a). The contingency plan should include
   - a conceptual design of the landfill gas control systems;
   - detailed plans, specifications and descriptions for the design, operation,

and maintenance of the contingency plan;
- an impact response plan describing the activities to be carried out in the event of an unacceptable increase in volatile compound concentrations within the buffer area, off site, or within the facility buildings or enclosed structures; and
- procedures for notification of the jurisdiction of authority of a landfill gas incident and of the subsequent implementation of the contingency plan.

D.2 Release of Landfill Gases to the Atmosphere

The release of gases from an engineered hazardous waste landfill facility is generally low, but an assessment of the potential of landfill gas generation and release to the atmosphere should still be completed.

D.2.1 Design factors for air emissions control systems

When designing an air emissions control system, a number of factors should be considered:

- the presence of low permeability soil or a bottom liner system (either may prevent the lateral migration of landfill gas),
- the levels of leachate within the facility,
- the facility configuration (e.g., the landfill slopes, vertical position of the landfill, and ratio of the landfill surface to volume of waste),
- the characteristics and limitations of the final cover,
- the phasing of landfilling and the closure operations for each area of the facility,
- the type and procedures for daily or intermediate cover (which affect hydraulic and landfill gas movements within the facility), and
- any activities to control or alter the moisture content within the facility.

An engineered hazardous waste landfill facility should not be established without documentation of plans, specifications and descriptions for

- the landfill gas collection systems including all active gas extraction and pumping systems;
- the landfill gas burning, treatment or utilization systems, and
- landfill gas system monitoring and operation.

Such a document should also be considered for an expansion of an engineered hazardous waste landfill facility including, but not limited to: an alteration, enlargement or extension of area or volume; or approving / permitting additional hazardous waste types / classes for disposal in an existing facility.

D.2.2 Landfill gas collection systems

The documentation should contain plans, specifications and descriptions of the design of the landfill gas collection system, including

a) the collection system, together with the collector orientation, layout and spacing; the depth(s) of placement within the landfill site; and the radius of the capture zone;
b) the gas collection pipes, together with the size, the material, the perforations, the granular bedding/envelope and the provisions for stress relief and settlement;
c) the header and gas transmission pipes, together with the size, the material, the slope, the valving, the access chambers, the condensate control systems, the seepage protection systems, the systems

for protection from freezing, the bedding and the provisions for stress relief and settlement; and
d) the condensate drainage, storage and disposal systems.

D.2.3 Landfill gas burning, treatment or utilization systems

The documentation should contain plans, specifications and descriptions of systems for landfill gas burning, treatment or utilization, including

a) provision for the ongoing analysis of the landfill gas;
b) systems for landfill gas extraction including any active pumping system to draw gas to the burning, treatment or utilization system and any moisture removal and gas treatment;
c) systems for any utilization of the collected landfill gas; and
d) systems for any gas flaring, with specifications for
    - the type and design of the flare device,
    - the design combustion temperature and residence time,
    - the destruction efficiency of volatile organic compounds and mixtures, and
    - the operational control systems (such as the temperature and combustion air controls, the flame failure detection system, the automatic ignition system and the flame arrestor).

D.2.4 Landfill gas system monitoring and operation

The documentation should contain plans, specifications and descriptions of the operation, monitoring and maintenance of the landfill gas system, including

a) the phasing and timing of the system installation, start-up and operation (to allow coordination of these tasks with the overall facility operation and to maximize landfill gas control);
b) the inspection frequencies and maintenance and replacement procedures for system equipment;
c) the monitoring of landfill gas flow rates and concentrations; and
d) the contingency plans that should be followed in the event of unexpected component failures.

Performance monitoring procedures for landfill gases should be established as described in Section I.4 of Appendix I

Landfill Liners

These Guidelines are a model set of technical requirements. They come into effect only if adopted, in whole or in part, by a jurisdiction of authority. Even where these Guidelines have been either completely or partially adopted by a jurisdiction of authority, the application of the guidelines are subject to any restrictions or conditions that are in place or could be added by that jurisdiction of authority. Readers of these Guidelines should check with the jurisdiction of authority to see whether any of these Guidelines currently apply. The specific requirements of the applicable jurisdiction of authority should be incorporated into the design and operation of the engineered hazardous waste landfill facility.

An engineered hazardous waste landfill facility design considers both the natural setting and engineered systems to contain or control contaminant migration. The attributes of a natural environment may be used in place of engineered systems if they achieve an equivalent level of protection for the environment and human health.

Liners help to contain or control the movement of liquids and hazardous materials from a waste disposal site into the groundwater systems. Liners also help to contain or control the movement of landfill gases.

An engineered liner system tends to be composed of more than one type of liner. Each liner material has advantages and disadvantages, so two liners are often used together to form a composite liner.
Often more than one composite liner system is used in an engineered liner design. Any leakage through the upper (primary) liner system can be detected and removed before the contaminants can pass through the lower (secondary) liner system.

An engineered hazardous waste landfill facility using a natural setting and/or engineered system to contain or control contaminant migration should not be established unless written documentation has been prepared describing the plans, specifications and descriptions for the construction, monitoring and maintenance of the appropriate landfill foundations and liners. Such a document should also be considered for an expansion of an engineered hazardous waste landfill facility including, but not limited to: an alteration, enlargement or extension of area or volume; or approving / permitting additional hazardous waste types / classes for disposal in an existing facility.

The requirements and specifications of liner systems are divided into two general areas:

- data collection, analysis and construction, and
- specifications, materials and installation.

This information can also be used for base construction of the natural setting.

E.1 Data Collection, Analysis and Construction

E.1.1 Data collection and design

The documentation should contain descriptions of the following:

a) the design and materials of construction for the foundation whether engineered system or natural, including a discussion of the capability of the foundation to support any expected static and dynamic loadings;

b) data on the fluctuations in the depth of the water table and its seasonal highs and lows with respect to the foundation of the natural and liner system;

c) sufficient data to evaluate the engineering properties of the natural or engineered foundation and the clayey liner materials, including:
   - the Atterberg limits (i.e., the consistency limits of clay materials, including the liquid limit, the plastic limit and the shrinkage limit),
   - the organic carbon content,
   - the grain size distribution,
   - the mineralogy,
   - the strength characteristics,
   - the hydraulic conductivity (*K*) or soil permeability (*k*),
   - the compressibility, and
   - the compaction curves, if applicable;

d) data to support an assessment of the likely change in hydraulic conductivity[1] of the natural and liner material, (e.g., in-situ clay, compacted clay, or geosynthetic clay) when it is:
   - in contact with or permeated by leachate or landfill gas and
   - under relevant effective stress conditions; and

e) data to determine if the protection layer above the geomembrane is likely to:
   - provide adequate long-term protection and, in particular,
   - limit (to less than 2%) the peak strain due to indentation caused by overlying materials (e.g., the leachate collection system gravel) under a short-term loading equivalent to the full weight of the overlying waste and cover.

E.1.2 Engineering analyses

The documentation should contain descriptions of engineering analyses based on data gathered through subsurface exploration and laboratory testing programs. These analyses should provide:

a) estimates of the total and differential settlement, including immediate settlement and primary and secondary consolidation (with particular attention paid to any maintenance holes);

b) estimates of the bearing capacity and stability of the foundation, along with evidence showing that the allowable bearing capacity of the foundation will not be exceeded (with particular attention paid to any maintenance holes);

c) estimates of the potential for bottom heave or blow-out due to hydrostatic or gas pressures;

d) evidence that the foundation is capable of providing adequate support for operating and construction equipment;

e) evidence that the side slopes of the landfill will be stable at all times during and following construction (allowing for all possible failure mechanisms); and

f) evidence that the waste slopes and underlying and adjacent liner materials

[1] If there is an increase in hydraulic conductivity following such interactions, the higher value should be used in any assessment of long term performance.

will be stable at all times during and following waste placement (allowing for all possible failure mechanisms).

E.1.3 Construction and testing

The documentation should also contain

a) a description of construction and installation procedures, and
b) a description of the methods and frequencies for inspection, monitoring, sampling and testing to be employed to assure that any foundation and liner(s) meet the design requirements.

E.2 Specifications, Materials and Installation

E.2.1 Liner system design

Unless an alternative design for groundwater protection is approved (or required), based on meeting criteria set by the jurisdiction of authority, the following guidelines should be used as minimum requirements in the design of a liner system for an engineered hazardous waste landfill facility:

a) any liner system should be installed to cover all the surrounding earth that is likely to be in contact with the waste or leachate; and
b) any liner system should consider at least two liners, together with leachate collection and removal systems above and between the liners. One of the liners may be the in-situ soil if it is equivalent to or better than a compacted clay liner. An equivalent system may be used if it is approved by the jurisdiction of authority.

E.2.2 Primary liner specifications

The following guidelines should be used as minimum requirements in the design of the primary (or upper) liner system:

a) The primary liner should be a composite liner consisting of a suitable protection layer (as discussed in Section E.1.1(e)) over an HDPE (high density polyethylene) geomembrane (GM) at least 1.5 mm in thickness. The GM should meet or exceed the following specifications:
   - does not exceed the oxidative induction time of the GM as determined by ASTM D3895-95 (as it may be amended from time to time), or
   - does not exceed the oxidative induction time of the GM as determined by ASTM D5885-95 (as it may be amended from time to time); and
   - the oxidative induction time should exceed 80% of the value for the original GM, after aging at 85°C for over 90 days, as described in ASTM D5721-95 (as it may be amended from time to time)
b) The GM should be underlain by either
   - a 0.75 m thick compacted clay liner (CCL) with a final equilibrium hydraulic conductivity (after interaction with leachate) of less than 10^{-9} m/s; or
   - an equivalent combination (in terms of leakage through holes or cracks in a geomembrane) of a geosynthetic clay liner (GCL) with a minimum coverage of 4.8 kg/m^2 of bentonite (or equivalent). The bentonite should not chemically react with the leachate, (e.g., do not use a sodium bentonite in a high chloride leachate). This GCL should be placed over a natural clay foundation or attenuation layer at least 0.6 m in thickness that has been compacted at the optimum

water content (as determined by a standard Proctor compaction test) and that has a hydraulic conductivity less than or equal to 10^{-7} m/s (a foundation or attenuation layer with equivalent performance may also be used). The assessment of the equivalence of the engineered liner systems may take into account the better contact between a GM and a GCL than CCL, but it should also consider the final equilibrium hydraulic conductivity of the GCL after interaction with leachate.

E.2.3 Secondary liner specifications

The following guidelines should be used as minimum requirements in the design of a secondary (or bottom) liner system,which should consist of:

a) a suitable protection layer (as discussed in Section E.1.1(e)) above the geomembrane (GM);
b) a GM with a recommended thickness of HDPE (high density polyethylene) of at least 2.0 mm (and with specifications that meet or exceed those given in Section E.2.2(a)) above a composite bottom layer;
c) a 5 m thick bottom layer consisting of one of the following choices:
    - a 1.5 m thick CCL (with a carbon content of at least 0.1% and a hydraulic conductivity of less than 5×10^{-10} m/s after interaction with leachate) over a 3.5 m thick or greater attenuation layer (with a hydraulic conductivity less than or equal to 10^{-7} m/s); or
    - a combination of a needle-punched GCL with a minimum of 4.8 kg/m^2 of bentonite over a 1.5 m thick CCL (with a carbon content of at least 0.1% and a hydraulic conductivity of less than 10^{-9} m/s after interaction with leachate) which is itself over a 3.5 m thick or greater attenuation layer (with a hydraulic conductivity less than or equal to 10^{-7} m/s); or
    - a 3 m thick CCL (with a carbon content of at least 0.1% and a hydraulic conductivity of less than 10^{-9} m/s after interaction with leachate) over a 2 m thick or greater attenuation layer (with a hydraulic conductivity less than or equal to 10^{-7} m/s); or
    - a 5 m thick natural clayey deposit (with a carbon content of at least 0.1% and a hydraulic conductivity of less than 10^{-9} m/s after interaction with leachate).

E.2.4 Liner system installation

The bottom slope of a natural or engineered liner system should be at a grade of at least 2% toward the nearest leachate collection pipes.

E.2.5 Liner system materials

Natural and engineered liners should be constructed of materials having appropriate chemical properties, strength and thickness to prevent failure due to any of the following causes:

a) internal erosion due to the leachate mounding that would occur if there were a failure of the leachate collection system;
b) contact (and reaction) with volatile organic compounds or leachate;
c) adverse climatic conditions;
d) heat generated by waste decomposition, hydration or chemical reactions in the waste; and
e) mechanical stress during installation and operations including (but not limited to)

punctures, settlement, compression, or uplift.

Any liner system should be placed on base materials capable of:

a) providing support and resistance to pressure from the overlying materials, and
b) preventing failure due to compression, uplift or settlement in the layers below any liner system.

E.2.6 Clay liner installation

The following guidelines should be used as minimum requirements in the design of any CCL. These guidelines are equally applicable for a natural clay setting to be used as a foundation or attenuation layer:

a) Details concerning the control of water content and dry density should be provided;
b) The lift thickness (i.e., the thickness of clay laid down at any one time) should not exceed 15 cm during construction (except for the bottom lift of a primary liner constructed over a leachate collection system, for which the thickness should not exceed 20 cm);
c) All lifts should be scarified (i.e., the surface of the clay should be roughed);
d) The equipment to be used should be specified;
e) No clods of clay or soil should be greater than 10 cm in diameter;
f) No stones should be larger than 5 cm in diameter; and
g) Procedures to avoid desiccation or freezing should be specified.

E.2.7 Liner system performance

Performance monitoring procedures for natural and engineered liner systems should be established both through leachate monitoring as described in Section I.1 of Appendix I and through groundwater monitoring as described in Section I.2 of Appendix I.

Leachate Management Systems

These Guidelines are a model set of technical requirements. They come into effect only if adopted, in whole or in part, by a jurisdiction of authority. Even where these Guidelines have been either completely or partially adopted by a jurisdiction of authority, the application of the guidelines are subject to any restrictions or conditions that are in place or could be added by that jurisdiction of authority. Readers of these Guidelines should check with the jurisdiction of authority to see whether any of these Guidelines currently apply. The specific requirements of the applicable jurisdiction of authority should be incorporated into the design and operation of the engineered hazardous waste landfill facility.

F.1 Leachate Collection and Leak Detection Specifications

An engineered hazardous waste landfill facility should not be established unless documentation of the plans, design and description of the proposed leachate control and leak detection and recovery systems is prepared. This should include estimates of leachate flows as well as designs for the drainage layer, the piping network and the leachate removal system. Such a document should also be considered for an expansion of an engineered hazardous waste landfill facility including, but not limited to: an alteration, enlargement or extension of area or volume; or approving / permitting additional hazardous waste types / classes for disposal in an existing facility.

The requirements and specifications for a leachate system is divided into three general areas:

- collection and leak detection specifications,
- alternative designs, and
- operation of detection and collection systems.

F.1.1 Leachate collection system

Leachate is collected above the uppermost liner material, or natural base if suitable, and conveyed by a network of perforated pipes to sumps or riser pipes for surface containment and disposal.

The following guidelines should be applied:

a) for any proposed leachate control and leak detection system, a leachate collection system should be
    - installed immediately above the uppermost liner, and
    - designed to be functional over the effective lifetime of the leachate generated at the facility.
b) unless an alternative design for groundwater protection is approved, (or required), based on meeting criteria set by the jurisdiction of authority, any leachate collection system should be
    - separated from the waste by a suitable nonwoven needle-punched geotextile or granular filter;
    - designed to be at least 0.5 m thick on the base and 0.3 m thick on the side slopes;

- constructed from gravel with a D_{85}[2] of not less than 37 mm, a D_{10} of not less than 19 mm, a uniformity coefficient (D_{60}/D_{10}) of less than 2.0, and with not more than 1% of the material (when measured by weight) able to pass a US#200 sieve size; and
- operated so that the leachate depth over any liner does not exceed 0.3 m at any point.

c) the leachate collection and leak detection systems should be
   - installed with a slope towards the collection pipes at a grade of at least 2%;
   - constructed of materials that are chemically resistant to the waste placed in the facility and to any leachate and landfill gases generated by the waste; and
   - hydraulically designed to account for any precipitation that may occur before the cover is installed.

d) the wrapping of collection pipes in geotextiles is **not** permitted.

e) the drainage materials surrounding the systems should
   - have sufficient strength to resist failure due to the pressure of overlying loads (including the equipment used at the facility), and
   - be designed and constructed to prevent clogging during the contaminating life span of the facility.

f) a suitable granular or geosynthetic filter should be placed between the waste and the granular blanket underdrain.

g) the side slopes of the leachate collection system should be designed to remain stable during installation, waste placement and settlement.

h) a sheltered storage building or treatment location is required for the collected leachate.

[2] The distribution parameter D_{85} is the sediment diameter value at which 85% of the sediment particles are smaller in size (and therefore the remaining 15% is larger).

F.1.2 Leak detection and recovery system

Between each pair of liner systems, a leachate leak detection and recovery system should be installed. The following guidelines should be applied:

a) a leak detection and recovery system should be installed between the primary and secondary liner systems
   - to assess leakage through the primary liner, and
   - to control the leachate level on the secondary liner.

b) unless an alternative is approved, the leak detection and recovery system should be
   - separated from the overlying liner by a suitable nonwoven needle-punched geotextile or granular filter;
   - designed to be at least 0.3 m thick;
   - constructed from gravel with a D_{85} of not less than 37 mm, a D_{10} of not less than 19 mm, a uniformity coefficient (D_{60}/D_{10}) of less than 2.0, and with not more than 1% of the material (when measured by weight) able to pass a US#200 sieve size;
   - operated so that the leachate depth over any liner does not exceed 0.3 m at any point.

F.2 Alternative Leachate Collection and Leak Detection Designs

The following guidelines should be applied:

a) the service life of any alternative designs for the primary leachate collection or the leak detection and recovery systems should be at least equal to the contaminating life span of the engineered hazardous waste landfill facility. A leachate collection system has a finite lifespan which may be significantly shorter than the predicted contaminating lifespan of the facility. Therefore, it would be advantageous to design a system that can be replaced as many times as required and with minimal effort.

b) any alternative design for the leachate collection and leak detection systems should have
   - a blanket drain of granular material with a minimum hydraulic conductivity of 10^{-1} m/s;
   - a minimum thickness of 0.5 m (yielding a transmissivity of at least 5×10^{-2} m^2/s under load);
   - all granular material sized such that not more than 1% (when measured by weight) is able to pass a US #200 sieve size;
   - similar capacities to transmit leachate under the relevant gradient if used on side slopes; and
   - no synthetic materials (e.g., geonets) used as replacements for the granular drainage blanket on the landfill base.

F.3 Operation of Leachate Collection and Leak Detection Systems

The following guidelines should be applied:

a) the collection pipes should be accessible for cleaning and inspection.

b) each collection or recovery system should
   - remove liquid or leachate regularly or continuously such that the static head of liquid or leachate is no more than 0.3 m (over the liner),
   - include a dedicated sump or pumping system and a back-up means of removing leachate if the primary system fails, and
   - allow the measurement of the volume of liquid removed from the system.

c) the operation of the leak detection and recovery system should not adversely affect the groundwater flow at the site.

In addition, performance monitoring procedures for the leachate collection systems should be established as described in Section I.1 of Appendix I.

Operational Procedures

These Guidelines are a model set of technical requirements. They come into effect only if adopted, in whole or in part, by a jurisdiction of authority. Even where these Guidelines have been either completely or partially adopted by a jurisdiction of authority, the application of the guidelines are subject to any restrictions or conditions that are in place or could be added by that jurisdiction of authority. Readers of these Guidelines should check with the jurisdiction of authority to see whether any of these Guidelines currently apply. The specific requirements of the applicable jurisdiction of authority should be incorporated into the design and operation of the engineered hazardous waste landfill facility.

All operations at an engineered hazardous waste landfill facility should be guided by the procedures detailed in an operating manual prepared specifically for the facility. The requirements and specifications are divided into six general areas:

- administrative procedures;
- procedures for waste placement;
- procedures for leachate collection, leak detection and leak recovery;
- contingency plan procedures;
- emergency procedures; and
- human resources procedures.

G.1 Administrative Procedures

An engineered hazardous waste landfill facility should not be established unless documentation is maintained at the facility that describes procedures for

- administrative record keeping,
- operational record keeping,
- facility operations,
- emergency response and site security,
- health and safety,
- public relations, and
- professional development.

Such a document should also be considered for an expansion of an engineered hazardous waste landfill facility including, but not limited to: an alteration, enlargement or extension of area or volume; or approving / permitting additional hazardous waste types / classes for disposal in an existing facility.

G.1.1 Administrative record keeping
The documentation should provide a clear identification of the chain of authority, organizational structure, job descriptions and job responsibilities for all personnel.

G.1.2 Operational record keeping
The documentation should provide an itemization of internal written reporting requirements and record keeping including (but not limited to)

a) all waste manifests or movement documents, with
    - the name and address of the owner of the waste,
    - the name of the carrier,
    - the nature of the substances present in the waste and their concentrations,
    - the origin of the waste,
    - the quantity of waste in metric tonnes, and
    - the date the waste was received;

b) a daily log of the placement location of all interned wastes;
c) a daily log of the volume and locations of leachate collected;
d) a daily log of all relevant site activities, including (but not limited to)
    - maintenance work, inspections and inspection findings;
    - security inspections and findings;
    - general inspections and findings (including but not limited to leachate seep detection from the landfill or landfill cover);
    - waste testing and results;
    - staff training and results;
    - leachate treatment, storage and disposal; and
    - performance monitoring and results.

G.1.3 Facility operations

The operating manual should be the primary information source for all aspects of facility operations and should be available to all personnel for convenient reference. It should be revised and updated on a regular basis as new procedures are developed to cope with changing market, environmental or regulatory conditions. This manual should contain descriptions of

a) the routine engineered hazardous waste landfill facility operational procedures (including laboratory procedures),
b) the waste materials inventory control and record-keeping system developed for the facility and rigorously followed at the facility, including details of procedures for
    - checking and filing the manifest or movement documents for incoming waste deliveries,
    - recording the weigh-scale and laboratory analysis data of incoming deliveries for internal inventory control (and for billing purposes as required),
    - evaluating the discrepancies between predicted and actual waste density, and
    - producing the "as built" drawings of completed landfill cells, including the recorded dates of placement, the operating staff responsible, and the types and sources of wastes placed therein.
c) the vehicle and equipment maintenance procedures for all mobile and stationary equipment on the facility, and
d) the equipment decontamination procedures and the personnel protection measures that are required for maintenance work, including
    - training requirements,
    - waste handling and treatment requirements and procedures, and
    - quality assurance / quality control (QA/QC) performance evaluations and the required criteria.

G.1.4 Emergency response and site security

The documentation should provide descriptions of

a) the emergency preparedness plans for each foreseeable event associated with facility operations;
b) the initial facility training and emergency preparedness training programs for facility staff, together with the levels of performance required for successful completion;
c) the ongoing training and emergency preparedness programs for each job responsibility, together with the levels of performance required for successful completion; and
d) the site security protocols.

G.1.5 Health and safety

The documentation should provide descriptions or copies of

a) the facility health and environmental monitoring programs together with their reporting requirements;
b) the health and safety precautions and procedures for facility personnel;
c) the initial and ongoing medical health and safety screening programs for each job responsibility; and
d) a list of authorities to notify in case of mishaps.

G.1.6 Public relations

The documentation should describe a public outreach program, including a predefined method for handling public comments and complaints.

G.1.7 Professional development

The documentation should describe an information exchange program that will facilitate staff awareness of

a) concerns about the operation, and
b) new developments in technology and management practices.

G.2 Procedures for Waste Placement

An engineered hazardous waste landfill facility should not be established until the following are prepared and documented:

a) procedures for limiting access to the site
    - to times when an attendant is on duty, and
    - to persons authorized to deposit waste in the fill area;
b) plans, specifications, and descriptions for the placement of waste, such as
    - placing waste in lifts of a specified thickness and compacting them with a mechanical rolling device as necessary to minimize subsidence of the completed landfill structure (although this requirement may not be appropriate when dealing with some solidified wastes), and
    - applying and compacting (where necessary) the daily and interim cover;
c) procedures to prevent the transport of contaminated or potentially contaminated materials from the facility;
d) procedures for handling off-site vehicles that could become contaminated by the active areas of the facility, including
    - preventing direct contact by off-loading the wastes away from the active areas, together with subsequently handling the wastes exclusively by on-site vehicles dedicated to working in the active area of the facility, and
    - washing all contaminated and potentially contaminated vehicles before they leave the facility (and the wash water should be treated as a hazardous waste unless proven otherwise).

Such documentation should also be considered for an expansion of an engineered hazardous waste landfill facility including, but not limited to: an alteration, enlargement or extension of area or volume; or approving / permitting additional hazardous waste types / classes for disposal in an existing facility.

G.3 Procedures for Leachate Collection, Leak Detection and Leak Recovery

The leachate collection, leak detection and leak recovery systems developed and implemented for the engineered hazardous waste landfill facility (during the construction, operation, maintenance, replacement, closure, and post-closure care of the facility) should include

a) a system to remove the pumpable liquids from within these systems to minimize the hydraulic head[3] on the bottom liner;
b) the determination of an action leakage rate[4] for the leak detection and recovery systems, considering the following factors:
    - uncertainties in the design (e.g., the slope, the hydraulic conductivity, and the thickness of drainage material);
    - the construction, operation, and location of the leak detection system (LDS);
    - the waste and leachate characteristics, together with the likelihood and amounts of other sources of liquids in the LDS; and
    - the action leakage rate should also consider the decreases in the flow capacity over time that result from factors such as silting and clogging, rib layover, creep of the synthetic components of the system, and overburden pressures;
c) an evaluation system to determine if the action leakage rate has been exceeded (e.g., the owner should convert the weekly or monthly flow rate from the monitoring data to an average daily flow rate in litres per hectare per day for each sump);
d) a weekly calculation of the average daily flow rate for each sump during the contaminating lifespan (i.e., during the active and closure periods);

[3] The "hydraulic head" of a fluid is the pressure in the fluid (measured as the vertical height of fluid).
[4] The "action leakage rate" is the maximum leakage rate through the liner (measured in the leak detection system) before contingency measures need to be implemented.

e) a monthly calculation of the average daily flow rate for each sump during the post-closure care period; and
e) a trigger mechanism where the liquid recovery in excess of the action leakage rate would prompt contingency procedures.

G.4 Contingency Plan Procedures

The contingency plan should incorporate plans, specifications and descriptions identifying contingency measures and procedures for use at the engineered hazardous waste landfill facility:

a) The plan should include a predictive monitoring program with trigger levels to initiate predefined
    - notification requirements,
    - investigative activities,
    - responses, and
    - pre-approved remedial activities by the jurisdiction of authority.
b) the plan should include procedures for predicting the effects of the facility at property boundaries, on surface water bodies and on underlying aquifers (including increases of contamination above background levels and the activities for remediating or restoring the affected lands or features).
c) the contingency plan should employ a computer model that can reasonably predict contaminant concentrations within a five-year timeframe during the contaminating life span of the facility. The model should include contaminant attenuation processes. Performance monitoring of the site should be used to confirm the accuracy of the model. Unexpected responses should trigger a review procedure to account for the inability of the model to predict the actual

system performance, and this may in turn require justification for continued facility operation in light of the system non-performance.

d) the plan should contain a program to continuously review and modify any studies and models developed for the facility (if necessary). Revision of models should not be accepted without a defensible explanation for the modification and should include testing to verify the evaluation of the modelling.

e) The plan should describe the contingency measures to be implemented
    - if the collected leachate exceeds a predefined quantity or quality limit,
    - if a liner or leachate system fails, or
    - if leachate leaves the waste fill zone in a quantity greater than expected or with a quality worse than expected.

f) The plan should describe the on-going training required of each employee for any and all foreseeable contingency plans, as well as the criteria required for successful completion of this training.

g) The plan should describe the groundwater performance monitoring program and identify monitoring locations.

G.5 Emergency Procedures

Emergency training and procedures should address (but are not limited to):

a) shutting down the engineered hazardous waste landfill facility and implementing immediate response measures;

b) choosing communication networks to be used in emergencies;

c) notifying
    - police departments in the vicinity;
    - fire departments in the vicinity;
    - emergency response teams and their roles and responsibilities;
    - ambulance and medical services;
    - contractors carrying on business in the vicinity;
    - schools, hospitals, local residents, and other relevant public or private establishments; and
    - the jurisdictions of authority;

d) evacuating facility staff;

e) taking inventories of the spill response and cleanup equipment that is available
    - at the facility;
    - from contractors carrying on business in the vicinity;
    - from agencies operating in the vicinity; and
    - from regional suppliers;

f) appointing one person and at least one alternate to act as an Emergency Response Coordinator (with authority to carry out action in accordance with the contingency plan);

g) reporting emergency incidents;

h) providing a copy of the contingency plan to
    - the Emergency Response Coordinator;
    - each alternate Emergency Response Coordinator;
    - the director or a manager of the facility;
    - CANUTEC (the Canadian Transport Emergency Centre, operated by Transport Canada); and
    - all nearby agencies such as local police and fire departments, relevant jurisdictions of authority emergency response teams and local hospitals;

i) training staff in the location and the proper use of all safety equipment and emergency supplies, including
    - clean-up equipment, sorbents and other materials; and

- protective equipment and clothing for all emergency response staff at the facility, appropriate for all the types of hazardous wastes managed at the facility; and

j) organizing sufficient drills or exercises to ensure that the staff members are proficient with safety equipment and emergency procedures.

G.6 Training, Documentation and Medical Testing of Personnel

G.6.1 Personnel training

Programs should be developed and implemented in the areas of job and safety training. These programs should be taught by qualified and experienced instructors, and meeting a predefined performance criterion should be required for the successful completion of each training program. As a minimum, the training program should teach

a) landfill concepts and day-to-day facility operating procedures;
b) hazardous material and hazardous waste awareness (WHMIS), together with proper handling, storage, and disposal practices;
c) legislative requirements that apply to the operations;
d) equipment operating instructions and safe practices;
e) emergency procedures plans;
f) best practices for wearing and testing protective clothing and equipment;
g) appropriate personal hygiene measures such as washing, eating and laundering;
h) first-aid and rescue measures;
i) procedures for using, inspecting, repairing and replacing emergency and monitoring equipment at the facility, including
    - automatic waste feed cut-off systems,
    - communications or alarm systems,
    - equipment for fires or explosions,
    - equipment for groundwater and surface water contamination incidents, and
    - equipment for shutdown of operations;
j) specific tasks to personnel responsible for post-closure care (when applicable) in the areas of
    - monitoring of air quality, leachate collection and treatment, gas collection and treatment (where applicable), surface runoff quality and control, groundwater quality, and integrity of final cover;
    - record keeping;
    - identification and proper disposal of all hazardous wastes and hazardous materials remaining at the facility at time of closure;
    - reporting in cases of non-conformance; and
    - remediating in situations of non-compliance.

In addition, there should be ongoing planned and unplanned training reviews for the items listed above. A predefined and objective QA/QC monitoring program for training should be put in place for each staff member.

G.6.2 Personnel documentation

Documents containing the following information should be maintained:

a) a job title for each position related to hazardous waste management, and the name of the employee filling each job;
b) a job description for each position, including specific descriptions of the education, skill and experience required;
c) a description of the introductory and continuing training that is given to each person filling a particular position;

d) documentation showing that the facility personnel have the training or job experience required for their positions;
e) complete records of job training for current personnel, which should be kept until closure of the facility; and
f) complete records of job training for former employees, which should be kept for a reasonable period of time (such as two years from the date the employee last worked at the facility).

G.6.3 Medical testing of personnel

All personnel on the facility should be given

a) thorough medical examinations by a qualified medical practitioner prior to commencing employment,
b) predefined periodic medical examinations throughout the duration of their employment on the facility, and
c) any other medical examinations that may be required (e.g., by occupational health and safety legislation or regulations).

Site Security

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The engineered hazardous waste landfill facility should control access to the site and implement strict security measures. Such measures include (but are not limited to)

a) installing a barrier such as a chain-link fence topped with barbed wire;
b) posting signs on the fence to identify the site and to warn trespassers;
c) installing a 24-hour surveillance system that continuously monitors and controls entry to the facility;
d) funnelling all traffic through a single control point for verification of manifests and movement documents, for load sampling, and for other jurisdiction of authority requirements or administrative actions;
e) posting the name of the site owner, contact telephone number(s), the name of the site operator, contact telephone number(s), in case of an emergency;
f) Posting emergency telephone numbers for the police, fire, environmental spills / response;
g) securing all valves, pumps, electrical systems and other operational controls that would be accessible to unauthorized personnel if other facility security measures were breached;
h) posting an emergency telephone number throughout the facility for staff and visitors to call in case of a security breach, a fire, an explosion or an accident; and
i) posting signs at each entrance to the facility and at such other locations as the jurisdiction of authority may deem warranted, legible from a reasonable distance (such as 10 metres), and reading as follows:
   - "DANGER — UNAUTHORIZED PERSONNEL KEEP OUT — HAZARDOUS WASTE FACILITY",
   - "DANGER — AUTHORIZED PERSONNEL ONLY — HAZARDOUS WASTE FACILITY", or
   - "RESTRICTED AREA — AUTHORIZED PERSONNEL ONLY — HAZARDOUS WASTE FACILITY,"

Performance Monitoring

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Performance monitoring is key to the successful operation of an engineered hazardous waste landfill facility. This section is divided into four subject areas:

- leachate monitoring,
- groundwater monitoring,
- surface water monitoring, and
- monitoring of emissions to the atmosphere.

I.1 Monitoring of Leachate

Leachate monitoring complements the programs for groundwater and surface water monitoring (see Sections I.2 and I.3). It provides important information for the assessment of facility performance as well as for the design of future facilities.

An operations plan for an engineered hazardous waste landfill facility should include a program for monitoring both the quality and the quantity of the leachate. This program should include descriptions of

- sampling, analysis and response procedures,
- assessment and reporting procedures, and
- the regulatory requirements that apply to leachate monitoring.

I.1.1 Sampling, analysis and response procedures

To characterize the leachate(s) being produced and the source materials being leached, the program should include the following procedures:

a) A sufficient number of representative samples of extractable liquids should be taken from within the waste or from the primary and secondary leachate collection systems. At a minimum, water quality samples should be obtained quarterly. These samples should be analyzed for the parameters listed in the Canadian Environmental Quality Guidelines of the CCME or in accordance with the applicable jurisdiction of authority requirements. If the concentration of a specific compound at a specific sampling point exceeds a predefined limit, it should trigger an investigation and may potentially initiate implementation of contingency measures.
b) The output liquid from the leak detection / secondary leachate collection system should be monitored for flow and physical, chemical and toxicological

characteristics. These parameters should be compared to predefined limits that could trigger contingency measures, including (but not limited to) the cessation of landfilling[5]. The source(s) of the output liquid(s) should be determined and clearly demonstrated to the jurisdiction of authority.

To characterize the level of leachate mounding, representative measurements a minimum of the height of leachate mounding in the deposited waste and in any leachate collection system should be taken on four occasions per year (at a minimum). If the height of mounding exceeds predefined levels, then contingency measures may be implemented. This sampling should evaluate the impacts of external effects such as large regional storm events.

I.1.2 Assessment and reporting procedures

An annual report should be produced containing the results of the leachate monitoring, an assessment of these results, the corrective actions taken in response, and the relative success of the corrective actions. This report should include

a) an assessment of the sources of the leachate contaminants;
b) an assessment of the compatibility of the leachate with the facility elements and engineered components;
c) an assessment of the differences in the leachate quality in different cells of the facility and the acceptability of partial or complete mixing of these liquids;
d) a description of the contingency measures that will be implemented if the predefined leachate concentration limits are exceeded, including (but not limited to) either the cessation of the landfilling of specific wastes or the complete cessation of landfilling at the site (depending on the outcome of corrective measures);
e) an assessment of the effects of any leachate mounding, including predicted and measured heights of leachate mounding as well as explanations for any differences;
f) an evaluation of the efficiency of the collection system;
g) a description of any corrective measures taken against leachate mounding and their effectiveness;
h) an assessment of the need to amend any sampling or analysis parameters (chemical or physical);
i) an assessment of the need to amend the design or operational procedures of the site; and
j) an assessment of the need to implement a contingency plan.

Additional reports may be produced to justify amending the parameters and frequency of monitoring. The owner may prepare reports showing that alternative provisions are appropriate based on conditions such as geographic location, climate, and the type of waste to be deposited at the facility.

I.1.3 Regulatory requirements

If the operator is treating leachate and disposing of the treated effluent into a local water body off the facility site, then the following requirements should be included in the operating license of the facility:

a) The quality of the treated leachate prior to disposal should meet the Canadian Environmental Quality Guidelines of the CCME or the requirements of the applicable jurisdictions of authority.

[5] Contingency measures may require alternative landfilling arrangements.

b) An assessment should be completed of the effects of the treated leachate on the receiving water body. This assessment should be based on the expected quality and quantity of leachate to be discharged, and should include the effects of priority pollutants, unlisted pollutants (such as medications), and pollutants that bioaccumulate or pose other problems due to long-term exposure.
c) All necessary regulatory permits from the jurisdiction of authority should be obtained for the disposal of the leachate to a water course or feature.
d) Written agreements should be signed with the owner(s) of the water body for the acceptance of the treated leachate discharge, including (but not limited to) any financial assurances that have been negotiated.
e) Analysis of priority organic pollutants that are not currently listed in the Canadian Environmental Quality Guidelines of the CCME or the requirements of the applicable jurisdiction of authority should be performed on an annual basis if such sources are accepted at the facility.

If the operator is treating and disposing of leachate off the facility site into an existing sanitary sewer or sewage works, then the following requirements should be included in the operating license of the facility:

a) The location(s) and owner(s) of the sanitary sewer and sewage works where disposal will take place should be listed.
b) The transportation or piping of the leachate to the sanitary sewer or the sewage works should be described.
c) The acceptance criteria for discharge to the sanitary sewer or the sewage works should be listed.
d) The discharge to the sanitary sewer and the sewage works should not be allowed to create a batch shock load on the receiving water body.
e) An assessment should be completed on the effects of the effluent discharge on the sanitary sewer and of the resulting sewage residue on the sewage works.
f) Any pretreatment required prior to acceptance of the leachate should be described.
g) Performance monitoring requirements for the effluent should be described.
h) All necessary regulatory permits from the jurisdictions of authority should be obtained for the disposal of the leachate to the sewage works.
i) Written agreements should be signed with the owner(s) of the sanitary sewer and sewage works for acceptance of the leachate, including (but not limited to) any financial assurances that have been negotiated.

I.2 Monitoring of Groundwater

Regular monitoring of groundwater is necessary to demonstrate that an engineered hazardous waste landfill facility is performing as designed and that the impacts on the environment are acceptable.

An effective monitoring program will be based on a sound understanding of the groundwater flow system in the area. This information should be available from the hydrogeology studies conducted during the site evaluation phase of the engineered hazardous waste landfill facility project.

A program for monitoring groundwater quality should determine both the potential and the rate of migration of hazardous waste (or its constituents) from the facility through the groundwater. The monitoring problem may be divided into two stages:

- from the facility to the uppermost aquifer, which requires best estimates of the water balance and the geological, chemical and physical characteristics of the unsaturated zone; and
- from the uppermost aquifer to other hydrogeological units (including aquifers), to a water supply well or a surface water body, which requires best estimates of the geological, chemical and physical characteristics of the saturated zone as well as the proximity of the facility to water supply wells or to surface water bodies.

I.2.1 Groundwater monitoring wells

A facility operations plan should ensure that groundwater quality and quantity are monitored. The groundwater monitoring program should incorporate the following specifications:

a) Monitoring wells should be installed hydraulically upgradient (i.e., upstream) of the limit of the waste areas. The number, locations, depths, screen lengths, and construction requirements of the upstream monitoring wells should be sufficient to yield measurements or samples that
   - are representative of the background groundwater quality in the relevant aquifer or hydrostratigraphic zone(s), and
   - are not yet affected by the facility.

b) Monitoring wells should be installed hydraulically downgradient (downstream) of the facility in the flow pathways that are the most likely to be affected by the facility operation. The number, locations, depths, screen lengths, and construction requirements of the monitoring wells should be sufficient to ensure that they immediately detect any statistically significant amounts of hazardous waste constituents that migrate from the facility.

c) Monitoring systems such as lysimeters should be installed beneath the base of the landfill, (if possible), to evaluate the potential leakage through the base of the landfill. These monitoring systems when constructed should have a negligible impact on the lifetime performance of the landfill (i.e., avoid any integrity decay of monitoring system). However, if possible, such systems give a direct measure of the performance of the landfill system at a crucial location and merit consideration.

d) All monitoring wells should be
   - installed using best available technology practices,
   - isolated within a single hydrostratigraphic unit,
   - constructed of materials that are non-reactive to the potential contaminants in the facility,
   - constructed with all as-built details recorded, and
   - registered with the jurisdiction of authority upon construction or abandonment (as required).

e) Monitoring wells should be assigned an effective lifespan based on the construction method used. Decommissioning of a monitoring well should occur at or before its effective lifespan limit, or if a well is damaged, unless an objective evaluation can certify the continued integrity of the well.

f) An objective annual assessment of the integrity of all monitoring wells should be completed and documented. This may include (but is not limited to) a download camera survey, a caliper log, and geophysical monitoring.

g) Static water levels from the groundwater monitoring wells should be measured daily, at representative wells, using pressure transducers. These levels should be confirmed monthly with manual measurements (possibly when the data loggers are being downloaded) and less frequently elsewhere, using appropriate methods.

I.2.2 Sampling and analysis procedures

a) A groundwater sampling and analysis plan should be developed that includes procedures and techniques for
   - sample collection,
   - sample preservation and shipment,
   - sample analysis,
   - chain of custody control of samples,
   - analytical requirements (CAEL or equivalent),
   - quality assurance / quality control requirements, and
   - maintaining a parameter list that includes (but is not limited to) the parameters listed in the Canadian Environmental Quality Guidelines of the CCME or in accordance with applicable jurisdiction of authority requirements.

b) The sampling and analysis plan should be reviewed and updated annually and incorporate all new
   - sampling techniques;
   - analytical techniques, and
   - jurisdiction of authority requirements for the parameter list.

c) Samples should be collected and shipped using accepted sampling and shipping methods (which may change from time to time).

d) Enough measurements of background concentrations should be obtained to establish statistical significance, so that trend analysis or comparable evaluations can be done reliably. To determine seasonal variations, a more intensive sampling frequency may be required in some cases (quarterly sampling over a three-year period is typically necessary to establish reliable baseline concentrations for each monitoring location). Trend analysis provides a reliable means to set predefined “trigger” levels for various levels of action.

e) Sampling frequency should be based on
   - the expected rate of contaminant migration;
   - the time required to successfully implement corrective, contingency or mitigative measures; and
   - predictive modelling (however, sampling should be conducted at least quarterly until the accuracy of the numerical model can be verified and used reliably to establish sampling frequencies).

f) The number of parameters monitored can be reduced (following the establishment of the baseline conditions) to those that are the least likely to be attenuated in the natural environment. The parameters selected should also have a leachate concentration that is markedly different from that present in the natural environment, such that a contaminant plume can be detected. These indicator parameters may then be used to assess the degree of contaminant migration once landfilling has begun operation. As a safety precaution, however, a full characterization should be completed annually. Comparable performance monitoring programs are permissible, subject to the approval of the jurisdiction of authority.

g) Other performance monitoring techniques should also be considered, including (but not limited to)
   - pore water squeezing of recovered soil cores (to monitor the rates of migration),
   - "tagged" waters released at the site (to monitor contaminant pathways),
   - "tagged" wastes using other tracers (e.g., ^{14}C-ringed compounds),
   - biological activity monitoring, and
   - chemical degradation monitoring.

I.2.3 Assessment and reporting of results

The assessment of the results for groundwater monitoring should be included in an annual report. This report should be prepared by a qualified professional and submitted within a reasonable period of time. The report should include

a) a statement of whether hazardous waste constituents have entered the groundwater;
b) the rate and extent of migration of hazardous waste constituents in the groundwater;
c) the concentration of hazardous waste constituents in the groundwater;
d) the expected effects of hazardous waste constituents on groundwater at the facility and on any aquifer affected by leachate or sediment from the facility ;
e) an assessment of the sampling results for groundwater relative to the predicted results, as well as a rationale for any measured deviations from the predicted results;
f) an assessment of any corrective measures taken when predefined action levels were reached, and of the effectiveness of these corrective actions; and
g) an assessment of the need
   - to amend the frequency or location of sampling and analytical parameters;
   - to amend the design or operational procedures for the facility; and
   - to implement the leachate contingency plan.

I.2.4 Response plans for groundwater contamination

If a report is submitted containing a notification of a deviation of measured groundwater results from the predefined results or an acknowledgement of a potential release of contaminants to the environment, then the facility owner should develop and submit to the jurisdiction of authority a specific plan that describes any assessment or corrective action. This plan should be produced by a qualified professional within a reasonable period of time. These plans are of two types:

a) For responses to annual reports, the plan should include a proposed assessment program that specifies
   - additional groundwater monitor wells (including their number, depths and locations);
   - sampling and analytical methods;
   - evaluation procedures for assessment; and
   - an implementation schedule that should not exceed a reasonable period of time.
b) For responses to assessment reports, the plan should include
   - the corrective or contingency measures that will be implemented if the predefined concentration limits are exceeded (these measures may include either a cessation of the landfilling of specific wastes or a complete cessation of landfilling at the site, depending on the outcomes

of the specific corrective actions); and
- a schedule of implementation.

I.2.5 Exceptions to groundwater monitoring requirements

All or part of the groundwater monitoring requirements may be modified by the jurisdiction of authority. Such exemptions may be obtained if the owner can demonstrate to the jurisdiction of authority that there is a low potential for migration of hazardous waste constituents from the facility into groundwater aquifers or to surface water. The submission from the owner should be

a) written and should be submitted to the jurisdiction of authority,
b) a copy should also be kept at the facility, and
c) certified by a qualified person (e.g., a professional geoscientist, environmental engineer or equivalent).

The jurisdiction of authority may replace all or part of the current requirements for groundwater monitoring with alternative requirements if the jurisdiction of authority determines that these alternative requirements will sufficiently protect the environment and human health. The alternative requirements may be set out in an approved closure or post-closure plan or in an enforceable document.

I.3 Monitoring of Surface Water

Regular monitoring of surface water is necessary to demonstrate that an engineered hazardous waste landfill facility is performing as designed and that the impacts on the environment are acceptable. To be effective, the monitoring program should address discharges from surface water control facilities on the facility and the potential impacts of these discharges on the receiving water bodies.

I.3.1 Sampling and analysis procedures

The owner of an engineered hazardous waste landfill facility should ensure that a program is carried out for monitoring surface water quality and quantity. The sampling and analysis criteria and protocols that were discussed in more detail above for groundwater monitoring (in Sections I.2.2(a) and I.2.2(b)) are equally relevant for surface water monitoring. In addition, the surface water monitoring program should incorporate further specifications:

a) Permanent stream flow monitoring stations should be
    - established with a calibrated flow weir or equivalent measuring device both upstream and downstream of the facility, as well as at any outflow structure from the site;
    - equipped with continuous water level monitoring devices to accurately monitor the surface water flows; and
    - calibrated to the catchment area associated with each station and to the numerical model of the surface water system.
b) A weather station should be operated in the general proximity of the facility to monitor the critical parameters used as inputs for the surface and groundwater models. At the minimum, the monitored parameters should include hourly measurements of precipitation, temperature, wind direction, and wind speed as well as evaporation pan readings (or the equivalent).
c) A sample selection protocol should be established for the surface water and suspended solids (if any) leaving the facility or in any receiving surface water features (including upstream control locations):

- Sampling stations should be established upstream of the limit of the waste area. The number and location of the samples should be sufficient to be representative of the background characteristics of surface water near the facility (but should not be affected by the facility).
- Sampling stations should be established adjacent to the waste area. The number and location of the samples should be sufficient to be representative of the background characteristics of surface water near the facility (but should not be affected by the facility).
- Sampling stations should be established downstream of the facility at the limit of the waste area. The number and location of the samples should be sufficient to ensure that any hazardous waste constituents migrating from the waste area are immediately detected (if they are in statistically significant quantities).
- Sampling should be done quarterly, as well as for specific storm events (i.e., first flush).
- Samples should be analyzed for the parameters listed in the Canadian Environmental Quality Guidelines of the CCME or in accordance with applicable jurisdiction of authority requirements.

d) The benthic (i.e., bottom-dwelling aquatic) community present in surface waters may be affected by discharges from the facility. When appropriate (based on the surface water assessment), this community should be monitored for any changes due to contamination.

e) The sediment of the stream channels in surface water features may be affected if these features receive a discharge from the facility. When appropriate (based on the surface water assessment), the sediment should be monitored for any changes due to contaminant sorption or attenuation.

The parameters and frequency for monitoring may be amended if the owner prepares documentation showing that alternative provisions are appropriate. These amendments may be based on conditions such as geographic location, climatic conditions and the type of waste to be deposited at the site. Such amendments are subject to approval by the jurisdiction of authority.

I.3.2 Assessment and reporting of results

The assessment of the results of the surface water monitoring should be included in an annual report. This report should be prepared by a qualified professional and submitted within a reasonable period of time. The report should include

a) a statement of whether hazardous waste constituents have entered any surface waters;
b) the rate and extent of migration of hazardous waste constituents in the surface waters;
c) the concentration of hazardous waste constituents in the surface waters;
d) an assessment of the sampling results for affected surface waters relative to the predicted results, as well as a rationale for any measured deviations from the predicted results;
e) an assessment of the expected effects on surface waters at the facility and on any off-site surface water body that may be affected by leachate or sediment from the facility;

f) an assessment of any corrective measures taken when predefined action levels were reached, together with an assessment of their effectiveness; and
g) an assessment of the need
   - to amend the frequency or location of sampling and analytical parameters;
   - to amend the design or operational procedures for the facility; and
   - to implement the leachate contingency plan.

I.3.3 Response plans for surface water contamination

If a report is submitted containing a notification of a deviation of measured surface water results from the predefined results or an acknowledgement of a potential release of contaminants to the environment, then the facility owner should develop and submit to the jurisdiction of authority a specific plan that describes any assessment or corrective action. The plans are of two types:

a) For responses to annual reports, the plan should include a proposed assessment program that specifies
   - additional surface water monitoring stations (including their number and locations);
   - sampling and analytical methods;
   - evaluation procedures for assessment; and
   - an implementation schedule that should not exceed a reasonable period.
b) For responses to assessment reports, the plan should include
   - the corrective or contingency measures that will be implemented if the predefined concentration limits are exceeded (these measures may include either a cessation of the landfilling of specific wastes or a complete cessation of landfilling at the facility, depending on the outcomes of the specific corrective actions); and
   - a schedule of implementation.

I.3.4 Exceptions to surface water monitoring requirements

All or part of the surface water monitoring requirements may be modified by the jurisdiction of authority. Such exemptions may be obtained if the owner can demonstrate to the jurisdiction of authority that there is a low potential for migration of hazardous waste constituents from the facility via the surface water to the aquatic environment or to groundwater. The submission from the owner should be

a) written and submitted to the jurisdiction of authority,
b) a copy should be kept at the facility, and
c) certified by a qualified person (e.g., a professional hydrologist, aquatic biologist, environmental engineer or equivalent).

The jurisdiction of authority may replace all or part of the current requirements for surface water monitoring with alternative requirements if the jurisdiction of authority determines that these alternative requirements will sufficiently protect the environment and human health. The alternative requirements may be set out in an approved closure or post-closure plan or in an enforceable document.

I.4 Monitoring of Air Emissions and Landfill Gases

Emissions to the atmosphere that occur during facility operations will include dust from earth moving, excavation, the placing of wastes and the placing of the cover, as well as ambient and vented landfill gases and vapours. Although both this section and Section D.2 of Appendix D discuss the release of emissions to the air from the engineered hazardous waste landfill facilities, this assessment should not be confused with the underground migration of landfill gases discussed in Section D.1 of Appendix D.

I.4.1 Potential for Landfill Gas Generation

The main concern in assessing the potential for landfill gas generation is the production of toxic or flammable / explosive gases. This evaluation tends to be separated into two major categories being:

a) Methane generation; and
b) Toxic vapour generation.

The decomposition of organic material in an anaerobic environment may result in the production of methane gas. The evolution of methane production in solid non-hazardous waste landfill facilities is well documented and it is presumed that the same process sequencing would be equally applicable to a hazardous waste landfill facility assuming the toxicity of the environment does not inhibit biological activities. Performance monitoring for methane generation can follow traditional techniques. These may include (but not be limited to):

a) Ambient environmental conditions within the waste cell(s)
    - internal temperature
    - moisture content
    - oxygen content
    - partial gas pressures
    - waste cell saturation / leachate liquid level
b) Biological indicators within the waste cell(s)
    - biological oxygen demand
    - landfill gas composition sequencing / transition and depletion (i.e., O_2 > CO_2 > CH_4 environment)
    - biological respiration rate(s) (i.e., O_2, NO_x / NH_3 / N_2, CO_2, H_2, SO_X / H_2S, CH_4)
c) Gas production indicators
    - organic substrate for biological consumption (i.e., dissolved organic compounds within landfill liquids)
    - organic decomposition parameters (e.g., organic acid production in leachate or sampling wells)
    - biological activity as noted above

The principle mechanisms for toxic vapour generation are waste volatilization, biological degradation and chemical reaction. Volatilization and degradation processes are anticipated to be slow, therefore the landfill gas generation may persist for a long period of time (i.e., the contaminating lifespan).

Toxic products tend to inhibit biological activities. Most toxic organic wastes are relatively inert and precautions should have taken place to prevent chemical reactions within the waste cell(s) during emplacement. Thus, the expectation is that toxic vapour generation would be primarily from waste volatilization and can be treated as a diffusion controlled process.

As noted in Appendix D, landfill gas migration results from two processes being convection and diffusion. Convection within the landfill is generated by pressure gradients while diffusion is the movement of gas / vapours from high to low concentrations. Gas / vapour migration is restricted by the relative insolubility of the gas / vapour in the landfill liquid. Different gases / vapours will migrate differently in accordance with the waste characteristics. Thus, gas production and solubility will be influenced by the presence of other compounds. The gas / vapour characteristics will also influence movement since some vapours are denser than others affecting the ability to migrate within the landfill. This is especially true if the base of the landfill is saturated limiting the vertical movement of some compounds and may influence the operation of the facility in terms of fully dewatering the landfill. Landfill gas monitoring needs to consider the possibility of "layering" within landfill.

Landfill gas migration can be influenced by operations. For example, the construction of the final cover can limit vertical migration of the landfill gas and may promote lateral migration. Even the construction methods employed for the landfill are expected to have some influence (i.e., daily and interim cover requirements / design).

The ramifications of all operations (and operational changes) are important to consider when evaluating the site performance and the selection of appropriate site monitoring locations. As indicated above, performance monitoring locations may change as a result of changes to (or be otherwise influenced by) the site operations.

I.4.2 Sampling and analysis procedures

An engineered hazardous waste landfill facility operations plan should ensure that a program is carried out for monitoring the emissions from the facility to the atmosphere. The sampling and analysis criteria and protocols that were discussed in more detail above (in Sections I.2.2(a) and I.2.2(b)) are equally relevant for emissions to the air. Similarly, the data captured by the weather station referenced in Section I.3.1(b) will be equally useful when evaluating this aspect of the monitoring program. The sampling and analysis program should cover the following types of air emissions:

a) dust fall;
b) suspended particulate matter (using high-volume samplers);
c) reduced sulphur compounds, both ambient (i.e., in the surrounding air) and from landfill vent pipes;
d) hydrocarbons, both ambient and from vent pipes;
e) landfill gases and volatiles, both ambient and from vent pipes; and
f) other airborne contaminants as appropriate.

The sampling program can also consider the potential for gas / vapour generation as outlined above in Section I.4. Performance monitoring may require the evaluation of ambient environmental conditions within the landfill cell(s); biological activity and/or gas production indicators (see Section I.4). Evaluation of other sampling data such as the leachate quality may prove useful when assessing the potential for landfill gas generation.

I.4.3 Assessment of results

The assessment of the results for the air emissions monitoring should be included in an annual report. This report should be prepared by a qualified professional and submitted within a reasonable period of time. It should contain the same general assessment of results as outlined in Sections I.1.2, I.2.3 and I.3.2.

I.4.4 Response plans for contamination due to air emissions

If a report is submitted containing a notification of a deviation of the measured air emission results from the predefined results or an acknowledgement of a potential release of contaminants to the environment, then the facility owner should develop and submit to the jurisdiction of authority a specific plan that describes any assessment or corrective action. To develop plans that respond to potential or actual effects of the site on the surrounding air, the general procedure described in Sections I.2.4 and I.3.3 should be followed.

Notwithstanding the general procedure noted above, specific control systems for landfill gas generation can be passive or active and may include the following:

a) Passive systems
    - vent stacks,
    - gravel filled trenches, or
    - perimeter rubble vent stacks
b) Active systems
    - gas extraction wells / network, or
    - pressure gas control system (to flush gas away from points of impingement)

The principles associated with traditional landfill gas control at solid non-hazardous waste landfill facilities are equally applicable to hazardous waste landfill facilities (barring the need for post-collection treatment) and such systems may be considered for mitigative purposes. Based on the chemical composition, there may a need to consider the control and treatment of the collected gases prior to release into the environment. The chemical composition of the landfill gas may also dictate the construction specification required for any collection system (i.e., chemically aggressive or reactive considerations).

Active or passive landfill gas control deals with intercepting the migrating gas along pathway(s). Corrective actions should also consider the control of the source(s) of the landfill gases. The need to remove or otherwise influence the emplaced source(s) could prove more effective than merely intercepting the generated gases / vapours in the longer term. This is especially true, given the accuracy advocated in documenting the placement of wastes within the landfill. As noted above, corrective actions whether interim or longer term may include operational changes to the landfill (ex., permissible landfill fluid levels and/or removal volumes) to achieve optimum performance.

I.5 Physical Site Monitoring

Physical inspection of any and all aspects of the hazardous waste landfill facility is recommended as part of a sound operations and maintenance program. Where possible and practical**,** implementation of an inspection program is advocated. These inspections are designed to evaluate systems performance and initiate corrective actions if any sign of impending failure or faulty operation is detected. Physical inspections of the hazardous waste landfill facility systems should be completed and documented as part of the routine performance monitoring program. These include site security inspections, routine maintenance evaluations and integrity testing of facility systems.

Site safety / security inspection may include (but are not limited to) routine evaluation of:

a) integrity inspection of the perimeter fencing;
b) routine inspection of all signage for legibility and wear and/or vandalism;
c) integrity inspection of all facility locks or similar security systems for presence and functionality;

d) inspection of security / safety systems for functionality / practicality;
e) routine safety inspections for all necessary equipment; and
f) routine integrity inspection of the functionality of contingency / emergency systems.

Operations maintenance should follow a schedule that ensures routine inspection for integrity or wear items. Maintenance schedules should adhere to recommended manufacturer's requirements at a minimum, but allow for a more frequent evaluation depending upon the system use and conditions of use. The site maintenance should extend to all aspects for the hazardous waste landfill facility operation.

Of particular concern is an effective landfill seepage monitoring program. Seepage monitoring tends to be most prevalent at or near the base of the landfill. It is commonly associated with the "buildup" of hydrostatic pressure within the landfill (i.e., mounding) that induces a lateral hydraulic pressure on the landfill cover, if present.

Even when no hydrostatic mound exists within the landfill; a routine perimeter integrity inspection is warranted. Under unsaturated conditions vapour monitoring should be considered.

The final cover integrity inspection is designed to address desiccation of the barrier system. Routine monitoring, not unlike the liner leakage detection system, is required to ensure sound compliance. This assessment should also consider the impairment of the barrier due to the vegetative species present on cover.

The promulgation of a hydrostatic condition within the landfill should trigger a physical monitoring program designed to detect the presence of seeps from the landfill. This work may be conducted in association with emission testing since this type of monitoring would not be suspended because of the "mounding" but may be modified.

Any detected seep (assuming it is minor in nature) from the landfill should be adequately documented. This would presumably include water quality evaluation. More severe seepage may activate an emergency response. The logistics associated with either response need to be adequately defined during the development stage of the landfill design. Implementation of the necessary contingency plans would be triggered based on the results of this evaluation.

A routine final cover inspection should also address geotechnical stability issues such as slumping, bulging or "blow-out" conditions, wind blown or surface water erosion, ponding of water, or other similar geotechnical concerns. The evaluation should also employ appropriate indicators such as vegetation kill or distress. Therefore, the inspection needs to be performed by knowledge and experienced staff and adequately documented.

Closure and Post-Closure

These Guidelines are a model set of technical requirements. They come into effect only if adopted, in whole or in part, by a jurisdiction of authority. Even where these Guidelines have been either completely or partially adopted by a jurisdiction of authority, the application of the guidelines are subject to any restrictions or conditions that are in place or could be added by that jurisdiction of authority. Readers of these Guidelines should check with the jurisdiction of authority to see whether any of these Guidelines currently apply. The specific requirements of the applicable jurisdiction of authority should be incorporated into the design and operation of the engineered hazardous waste landfill facility.

J.1 Closure

An engineered hazardous waste landfill facility should ensure that written documentation is prepared describing the plans and activities for the closure of the facility and for the post-closure care of the facility. Confirmation of the proposed end use of the site potentially defined as early as the initial approval process should be finalized. This documentation should be completed not later than the date when 90% of the total waste disposal volume is filled or two years before the anticipated date of closure, whichever comes first. The documentation should include

a) a plan showing the appearance of the facility site after closure;
b) a description of the proposed end use for the facility site;
c) descriptions of the procedures for closure of the facility, including procedures for:
   - the advance notification of the engineered hazardous waste landfill facility closure to the public;
   - posting notification of the engineered hazardous waste landfill facility closure at the site entrance, together with notifications of alternative waste disposal procedures or locations (if any);
   - the completion, inspection and maintenance of the final cover and landscaping;
   - the security of the facilty;
   - the removal of unnecessary structures, buildings and amenities; and
   - the final construction of any control, treatment, disposal, and monitoring facilities (for leachate, groundwater, surface water and landfill gas);
d) descriptions of the procedures for post-closure care of the engineered hazardous waste landfill facility, including procedures for
   - the operation, inspection and maintenance of the control, treatment, disposal and monitoring facilities (for leachate, groundwater, surface water and landfill gas);
   - record keeping and reporting; and
   - complaints, responses and public relations;
e) an assessment of the adequacy of the contingency plans for leachate and landfill gases and of the need to implement them;

f) an updated estimate of the contaminating lifespan of the facility based on the results of the monitoring to date; and
g) the owner of the facility should provide to the jurisdiction of authority (for approval) an update of the cost estimates for financial assurance which should be based on the contaminating lifespan.

J.2 Post-Closure

An engineered hazardous waste landfill facility should ensure that an annual report is prepared within a reasonable period of time after each anniversary of the date on which waste was last placed at the facility. These reports should describe the post-closure care of the facility and should summarize the results of the monitoring programs. The annual post-closure care documentation should include

a) an interpretative analysis of the results of all leachate, groundwater, surface water and landfill gas monitoring, together with an assessment of the need to amend the monitoring programs;
b) assessments of the adequacy of the contingency plans for leachate and landfill gases and of the need to implement them;
c) assessments of the operation, maintenance and performance of the final cover and of any control, treatment, disposal and monitoring facilities (for leachate, groundwater, surface water and landfill gas) together with discussions of any corrective actions taken;
d) a summary of the data on the quantities of leachate that was either removed or treated and discharged from the facility;
e) assessments of the need to continue the control, treatment, disposal or monitoring of leachate, groundwater, surface water or landfill gas;
f) a summary of the public complaints received by the owner, the responses given and the actions taken;
g) an updated estimate of the contaminating lifespan of the facility, based on the results of the monitoring to the present time;
h) an update of the cost estimate for financial assurance; and
i) an assessment of the need to amend the frequency and period covered by the post-closure documentation (such changes should be based on long-term risk assessments that consider the possible failure of the containment structures).