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Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal
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Item 4 (b) (i) of the provisional agenda*

Matters related to the implementation of the Convention: scientific and technical matters: technical guidelines

Draft updated technical guidelines on specially engineered landfill (D5)

Note by the Secretariat

1. As is mentioned in the note by the Secretariat on technical guidelines (UNEP/CHW.14/7), Argentina and Canada, in consultation with the small intersessional working group on specially engineered landfill and incineration on land, updated the technical guidelines on specially engineered landfill (D5), as set out in the annex to the present note.

2. The changes made to the technical guidelines adopted by decisions II/13 and III/13[1] have not been indicated using the track-change function as the new document has been structured in a different manner to the original one. Therefore, a track-change version is difficult to generate in a readable format.

3. The present note, including its annex, has not been formally edited.

* UNEP/CHW.14/1.

[1] The previous version of the technical guidelines on specially engineered landfill is available on the Convention website: http://basel.int/Implementation/Publications/LatestTechnicalGuidelines/tabid/5875/Default.aspx.

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Annex

Draft updated technical guidelines on specially engineered landfill (D5)

Draft of 15 February 2019

Contents

Glossary

[To be added at a later stage]

Abbreviations and acronyms

AF	Anaerobic Filter
BAT	Best Available Techniques
BEP	Best Environmental Practices
BPA	Bisphenol A
BOD5	Biochemical Oxygen Demand 5 days
CECs	Contaminants of Emerging Concerns
COD	Chemical Oxygen Demand
ESM	Environmentally Sound Management
HBCD	Hexabromocyclododecane
HDPE	High-density polyethylene (plastic)
NMOCs	Non-methane organic compounds
OECD	Organization for Economic Co-operation and Development
PBDEs	Polybrominated diphenyl ethers
PFCs	Perfluororinated compounds
POPs	Persistent Organic Pollutants
PPCPs	Pharmaceuticals and personal care products
PVC	Polyvinyl chloride (plastic)
RO	Reverse Osmosis
TOC	Total Organic Carbon
UV	Ultraviolet

I. Introduction

A. Scope

1. The present technical guidelines provide guidance on the environmentally sound disposal of hazardous wastes and other wastes in specially engineered landfills, pursuant to decisions BC-13/6 and BC-14/[ ] of the Conference of the Parties to the Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal (hereinafter referred to as "the Convention"). This document supersedes the *Technical guidelines on specially engineered landfill* of September 1995.

2. These technical guidelines refer to "hazardous wastes" and to "other wastes" as defined in Article 1, paragraph 1 and 2 of the Convention, respectively. They apply to the disposal operation D5: Specially Engineered Landfills, in Annex IV.A of the Convention.

3. The term "engineered landfills for hazardous wastes" is used in the present document to refer to landfills designed for hazardous wastes while the term "engineered landfills for other wastes" refers to landfills for other wastes (i.e. wastes belonging to any category in Annex II to the Convention[1]). When needed, the term "engineered landfills" will be used to encompass both terms.

4. These guidelines provide:

(a) Overarching and common guidance on the location, design, operational procedures and closure of engineered landfills;

(b) Specific guidance for engineered landfills for hazardous waste and for engineered landfills for other wastes.

5. The disposal of hazardous wastes and others wastes subject to the disposal operation D1 ("Deposit into or onto land (e.g., landfill, etc.)") and D12[2] ("Permanent storage (e.g., emplacement of containers in a mine, etc.")) fall outside the scope of this document.

6. It should be noted that the present guidelines do not provide guidance on steps and procedures on upgrading engineered landfills that are not environmentally sound to bring them in line with the guidance provided in the present guidelines.

B. About deposit into or onto land and engineered landfills

7. Deposits into or onto land are used for the disposal of waste in most countries. If these deposits are not designed and operated in an environmentally sound manner they can present risks to human health and the environment.

8. Engineered landfills allow for the final disposal of hazardous wastes and other wastes in an environmentally sound manner with limited impact to water, air, soil, plants or animals, and for control over noise or odours without adverse effects on the landscape, places of special interest and the environment.

9. An engineered landfill includes a combination of natural protection and engineered systems that work together to provide long-term confinement and control of hazardous wastes and other wastes as necessary for the effective contaminating lifespan of these wastes. [The effective contaminating lifespan can be defined as the period of time which the landfill produces contaminates at a level that may have negative impacts on the environment if released.] Engineered landfills should be designed in accordance with the type of waste that will be disposed of and its effective contaminating lifespan.

II. Relevant provisions of the Basel Convention

10. The Basel Convention, which entered into force on 5 May 1992, aims to protect human health and the environment against the adverse effects resulting from the generation, management,

[1] Annex II covers "Wastes collected from households" (Y46) and "Residues arising from the incineration of household wastes" (Y47).

[2] Guidance on permanent storage is provided in the General technical guidelines on the environmentally sound management of waste consisting of, containing or contaminated with persistent organic pollutants (UNEP/CHW.13/6/Add.1/Rev.1) and Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with mercury or mercury compounds (UNEP/CHW.12/5/Add.8/Rev.1).

transboundary movements and disposal of hazardous and other wastes. It does this via a set of provisions on the transboundary movement of wastes and their environmentally sound management (ESM). In particular, the Basel Convention stipulates that any transboundary movement (export, import or transit) of wastes is permissible only when the movement itself and the planned disposal of the hazardous or other wastes are environmentally sound.

11. A set of provisions of the Basel Convention lays out Parties obligations to ensure the ESM of hazardous wastes and other wastes. These are outlined in paragraphs 12 to 14 below.

12. In Article 2 ("Definitions"), paragraph 1, the Basel Convention defines waste as "substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law". Paragraph 2 defines management as "the collection, transport and disposal of hazardous wastes or other wastes, including after-care of disposal sites". Paragraph 4 defines disposal as "any operation specified in Annex IV" to the Convention. Paragraph 5 defines approved site or facility as "a site or facility for the disposal of hazardous wastes or other wastes which is authorized or permitted to operate for this purpose by a relevant authority of the state where the site or facility is located". Paragraph 8 defines the ESM of hazardous wastes or other wastes as "taking all practicable steps to ensure that hazardous wastes or other wastes are managed in a manner which will protect human health and the environment against the adverse effects which may result from such wastes."

13. Article 4 ("General obligations"), paragraph 1, establishes the procedure by which Parties exercising their right to prohibit the import of hazardous wastes or other wastes for disposal shall inform the other Parties of their decision. Paragraph 1 (a) states: "Parties exercising their right to prohibit the import of hazardous or other wastes for disposal shall inform the other Parties of their decision pursuant to Article 13." Paragraph 1 (b) states: "Parties shall prohibit or shall not permit the export of hazardous or other wastes to the Parties which have prohibited the import of such wastes, when notified pursuant to subparagraph (a)."

14. Article 4, paragraphs 2 (a) – (e) and 2 (g), contains key provisions of the Basel Convention directly pertaining to ESM, waste prevention and minimization and waste disposal practices aimed at mitigating adverse effects on human health and the environment:

Paragraphs 2 (a) – (e) and 2 (g): "Each Party shall take appropriate measures to:

"(a) Ensure that the generation of hazardous wastes and other wastes within it is reduced to a minimum, taking into account social, technological and economic aspects;

(b) Ensure the availability of adequate disposal facilities, for the environmentally sound management of hazardous wastes and other wastes, that shall be located, to the extent possible, within it, whatever the place of their disposal;

(c) Ensure that persons involved in the management of hazardous wastes or other wastes within it take such steps as are necessary to prevent pollution due to hazardous wastes and other wastes arising from such management and, if such pollution occurs, to minimize the consequences thereof for human health and the environment;

(d) Ensure that the transboundary movement of hazardous wastes and other wastes is reduced to the minimum consistent with the environmentally sound and efficient management of such wastes, and is conducted in a manner which will protect human health and the environment against the adverse effects which may result from such movement;

(e) Not allow the export of hazardous wastes or other wastes to a State or group of States belonging to an economic and/or political integration organization that are Parties, particularly developing countries, which have prohibited by their legislation all imports, or if it has reason to believe that the wastes in question will not be managed in an environmentally sound manner, according to criteria to be decided on by the Parties at their first meeting;"

(g) Prevent the import of hazardous wastes and other wastes if it has reason to believe that the wastes in question will not be managed in an environmentally sound manner."

III. General considerations on environmentally sound management

15. ESM is a broad policy concept that is understood and implemented in various ways by different countries, stakeholders and organizations. The provisions and guidance documents pertaining to the ESM of hazardous wastes and other wastes provide for a common understanding and international guidance to support and implement the ESM of hazardous wastes and other wastes.

16. The 2013 *Framework for the environmentally sound management of hazardous wastes and other wastes* ("ESM framework") (UNEP, 2013) was adopted at the eleventh meeting of the Conference of the Parties to the Basel Convention.[3] The framework establishes a common understanding of what ESM encompasses and identifies tools and strategies to support and promote the implementation of ESM. It is intended as a practical guide for governments and other stakeholders participating in the management of hazardous wastes and other wastes and constitutes the most comprehensive guidance on ESM to complement the Basel technical guidelines.

17. As presented in paragraph 14 of this document, Article 4 of the Basel Convention contains provisions related to the ESM of hazardous wastes and other wastes. ESM is also the subject of the following declarations:

(a) The 1999 Basel Declaration on Environmentally Sound Management, which was adopted at the fifth meeting of the Conference of the Parties to the Basel Convention calls on the parties to enhance and strengthen their efforts and cooperation to achieve ESM, including through prevention, minimization, recycling, recovery and disposal of hazardous and other wastes subject to the Basel Convention, taking into account social, technological and economic concerns, and through further reduction of transboundary movements of hazardous and other wastes subject to the Basel Convention;

(b) The 2011 Cartagena Declaration on the Prevention, Minimization and Recovery of Hazardous Wastes and Other Wastes, which was adopted at the tenth meeting of the Conference of the Parties to the Basel Convention and reaffirms that the Basel Convention is the primary global legal instrument for guiding the ESM of hazardous wastes and other wastes and their disposal.

18. The Organization for Economic Co-operation and Development (OECD) has adopted a recommendation on ESM of wastes which includes various items, inter alia core performance elements of ESM guidelines applying to waste recovery facilities, including elements of performance that precede collection, transport, treatment and storage and also elements subsequent to storage, transport, treatment and disposal of pertinent residues (OECD, 2004).

19. Parties should develop a range of measures (strategies, policies, legislation, regulations and programmes) and monitor their implementation to support the meeting of ESM objectives. The implementation of national strategies, policies and programmes are effective tools to complement the implementation of legislation and regulations; monitoring and enforcement; incentives and penalties; technologies; and other tools in which all key stakeholders participate and cooperate (UNEP, 2013). The following sections should be taken into account when establishing, implementing or evaluating ESM.

20. The prevention and minimization of hazardous wastes and other wastes are the first and most important steps in their overall environmentally sound management. In Article 4, paragraph 2, the Basel Convention calls on Parties to "ensure that the generation of hazardous wastes and other wastes is reduced to a minimum". Waste prevention should be the preferred option in any waste management policy. According to the framework for the ESM of hazardous wastes and other wastes, the need to manage wastes and/or the risks and costs associated with doing so are reduced by not generating wastes and by ensuring that generated wastes are less hazardous.

21. The waste management hierarchy covers prevention, minimization, reuse, recycling, other recovery including energy recovery, and final disposal; in doing so, encouraging treatment options that deliver the best overall environmental outcome, taking into account life-cycle thinking.[4]

22. Disposing of waste in engineered landfills falls under final disposal and should therefore be one of the least favoured options after other options in the waste hierarchy have been duly considered. Nevertheless, engineered landfills are important because they can ensure that hazardous wastes and other wastes are separated from the environment.

IV. General guidance on environmentally sound disposal in engineered landfills

23. Environmentally sound management involves the use of facilities operated under quality assured management regimes, according to appropriate Best Available Techniques (BAT) and Best Environmental Practices (BEP). Planning, design, and building engineered landfills requires financial investment.

[3] UNEP/CHW.11/3/Add.1/Rev.1.

[4] Decision BC-10/2: Strategic framework for the implementation of the Basel Convention for 2012−2021.

24. To establish and operate engineered landfills requires that efforts by the responsible legal authorities have to be made, including regulatory law, administrative execution, financial incentives (e.g. landfill taxes) and subsidies (e.g. to provide lower, affordable tipping fees).

A. Legislative and regulatory framework

25. Most countries already have in place some form of legislation that outlines broad environmental protection principles, powers and rights. Such legislation should make ESM operational and include requirements for protection of both human health and the environment. Such enabling legislation can give governments the power to enact and enforce specific rules and regulations on hazardous wastes and other wastes, conduct inspections and establish penalties for violations.

26. A legislative and regulatory framework should be in place to ensure that engineered landfills are fully protective of the environment and human health. Such legislation should contain detailed requirements for the design, operation, closure and post closure of the engineered landfill. Examples of national legislation can be found in Annex I.

27. Specific components or features of a regulatory framework applicable to the requirements of an engineered landfill should include, at least:

(a) Specification of the design criteria for the protection of groundwater (e.g. liner and leachate collection system), size of the buffer area and site boundaries and requirements to undertake hydrogeological and surface water assessments;

(b) Specification of the design criteria for leachate, surface water, and gas management systems, nuisance and hazards (e.g. odours, dust, vermin, fire);

(c) Requirements for the operation, monitoring and maintenance such as waste acceptance criteria and procedures, daily cover, [surface water,] leachate and gas management, contingency plan, inspections, record keeping, annual report; and

(d) Requirements for the closure and post closure procedures such as closure plans, final cover, slopes design, reporting and monitoring procedures.

28. Examples of other aspects related to engineered landfills that could be regulated through legislation include:

(a) Siting provisions and requirements;

(b) General requirements for public participation;

(c) Workers training and safety requirements;

(d) Financial assurance for the operation, closure and post closure.

B. Location

29. An engineered landfill should be located on a site meeting specific environmental, technical and social requirements. Thus, environmental, social, legal and economic assessments should be conducted to select the best available site and an environmental impact assessment conducted. An engineered landfill suitability map listing the different sites and their suitability should be prepared using all of the relevant criteria to assist in the decision-making process.

30. Public consultations should be held with community members and other relevant stakeholders on the location of an engineered landfill and minimum separation distances. Community engagement strategies should be developed to reach the various stakeholders, including workers pursuing their livelihoods in the informal economy.

31. Identifying the location of an engineered landfill site and evaluating its suitability should be done by taking into account various criteria, including but not limited to, geological, hydrological, hydrogeological, biological, ecological, meteorological, archaeological, geotechnical, air quality, and ambient noise criteria (CCME, 2006). More specifically, evaluation and selection of an engineered landfill site should give consideration to climate, topography of the site, permafrost, seismically active areas, shorelines, wetlands, parks, and environmentally sensitive areas (ECCC, 2017).

32. Topography criteria for choosing a good site should include an adequate level area for waste receiving, processing, and storage activities; and a gradient allowing surface water runoff away from active portions of the site. No gullies or depressions should be present to prevent water collection unless diversion measures are undertaken.

33. An engineered landfill site should, when possible, be located:

(a) In an area that has a sufficient natural geological barrier;

(b) Away from a drinking water source. It should not be located upgradient or over an aquifer that represents the source of drinking water for a community;

(c) An engineered landfill site should be located on land which can bear the load of the engineered landfill without damaging the liner system and the drainage system;

(d) Away from geologically unstable areas such as seismically active areas to prevent damage to the engineered landfill infrastructures. Additional engineering measures should be put in place so that the systems can withstand anticipated earthquake loadings without failure;

(e) Away from environmentally sensitive areas which have sensitive flora and fauna, including threatened or endangered species. It should not be located in or near natural reserves and critical habitats;

(f) Away from a shoreline and above sea-level to protect the site from erosion. It should not be located within a flood plain subject to a risk of flooding greater than 1 in 200 years unless additional engineering measures are in place to withstand flooding conditions;

(g) In a way that the amount of transport of waste to the engineered landfill is minimized and within reasonable distance from major waste generators;

(h) On a permafrost-free area, or on thaw-stable permafrost to avoid the consequences of thawing on engineered landfill infrastructures, especially under a warming climate.

34. Consideration should be given to the general property boundary (EPA, 2007); distance between the facility and residential and public areas; and distance between the facility and heritage, cultural and archaeological sites to mitigate health and environmental risks to the community, as follows:

(a) The property boundary should be designed so that a minimal buffer zone between the operational area of the facility and public roadways and highways be maintained. A minimal buffer zone should be maintained between the active engineered landfill face and the property boundary;

(b) Engineered landfills containing biodegradable wastes should be located away from airports to prevent damage to aircrafts caused by birds. An engineered landfill should be located at a reasonable distance from residential, commercial and public areas to prevent impacts such as noise, traffic, birds, vermin and insects, odour dust, wind-blown materials, fires and depreciation of land value;

(c) A perimeter barrier should be built to prevent free access to the site and to prevent litter from spreading beyond the engineered landfill boundaries. The engineered landfill should be located downwind of the prevailing wind direction of the community. Future development of the area should be considered prior to siting a engineered landfill;

(d) An adequate distance from a heritage, cultural or archaeological site should be maintained to prevent frictions between the community and the waste facility.

C. Design

35. An engineered landfill design requires a geological barrier and a liner system, leachate and gas collection and treatment systems, cover systems, storm water and surface water management, division into multiple engineered landfill cells if appropriate, an environmental monitoring system, a transportation network with a capacity sufficient for the planned operations, and a plan for closure and aftercare.

36. Investigations should be conducted to obtain information on the site, including a geotechnical and a hydrogeological investigation (i.e., inspection of the conditions of the site, drilling investigation and soil sampling and testing). This should include an assessment of the pre-development soil conditions to aid in the development of reclamation/revegetation plans for the site closure, an assessment of waste volume and soil material balance to ensure an adequate supply of cover material, and geotechnical analysis of structures that will be used to contain waster and water.

37. The construction of all parts of the engineered landfill should be carried out in accordance with environmental practices for construction activities, with approved engineering design and specifications and follow quality assurance and quality control protocols to ensure that the design objectives are met. It should be performed under the supervision of a licensed professional engineer.

38. Pre-construction reports and plans should be prepared by a qualified engineer and include final design reports, construction drawings and specifications (e.g. material and work required) and construction quality assurance and quality control plan.

39. Post-construction reports, plans and records should also be prepared by a qualified engineer and include as-built drawings, project records of addenda reports, inspections, quality control certifications (e.g. for liner installation, soil layer etc.) and a certificate of completion report stating that the engineered landfill has been constructed as designed and outlining any deviation from the original design and the rationale for those deviations.

40. A screen should be used to hide the engineered landfill from view. Fences should also be installed around the waste facility e.g. to prevent access to the site and to contain wind-blown material.

[To be inserted: figure of an engineered landfill]

1. Geological barrier

41. An engineered landfill should be constructed on a location with a natural geological barrier below and in the vicinity of the engineered landfill site for the protection of soil and groundwater. This natural geological barrier should provide sufficient attenuation capacity and have a homogenous upper layer. The geological barrier reduces the migration rate of pollutants and leachates significantly, if the liner system becomes defective. The upper layer of a geological barrier should have a low hydraulic conductivity of at least [1.0 x 10-7 m/s / 1.0 x 10-6 m/s] and a thickness for landfills for hazardous wastes of at least [5 m /6 m] and for landfills for other wastes of at least [3m /6m], respectively.

42. In cases where the natural geological barrier is not in accordance with the previous paragraph and not able to reduce significantly the migration rate of pollutants and leachates to be considered environmentally sound, additional containment measures should be implemented. Compaction of the soil and/or the addition of materials with lower conductivity [of at least 1.0 x 10-8 m/s] are recommended. In such cases, it is also recommended that, prior to improvement, the upper layer of the natural underground should have parameters sufficient to significantly reduce the migration rate of pollutants and leachates, [i.e. a conductivity of at least 1.0 x 10-6 m/s and a good attenuation capacity.]

43. The lowest point of the additionally established layer for improving the geological barrier should be at least 1m, but preferably more, above the seasonal high-water table.

2. Liner system

44. In addition to a geological barrier, an engineered landfill should have a liner system covering the side slopes and the bottom of the cell. This system should hinder the leachate from flowing underground so that the leachate is lead through the drainage system to the outlet of the engineered landfill. Engineered landfills for hazardous waste should have a double-liner system, and engineered landfills for other wastes should have a single liner system unless the permeability of the geological barrier in addition to the single liner is not considered sufficient to protect the environment. The liner system should consist of impermeable or nearly impermeable layers and can be made for example of compacted soils, asphalt, synthetic materials or of a combination of materials. Each of the liners should be a composite liner: a mineral layer (e.g. compacted soil or clayish materials) [of a thickness of at least 0.50m; and a welded geomembrane of a thickness of at least 2.5mm]. The mineral liner for a landfill for hazardous wastes should have a conductivity of at least [1.0 x 10-10 m/s and for other wastes of at least 1.0 x 10-9 m/s]. Material of the geomembrane should be compatible with the chemical nature of the waste. There should be a reasonable buffer between the lowest point of the engineered landfill liner and the seasonal high-water table.

45. A drain system should be installed above the liner system to collect leachate, as they are likely to be contaminated.

46. Mineral layers and geomembranes in engineered landfills for hazardous wastes should be chosen carefully, according to the contaminant travel time in the materials considered and the level of risk it represents. In general, mineral layers should be thicker and have a lower hydraulic conductivity in engineered landfills for hazardous wastes than in engineered landfills for other wastes.

[To be inserted: Figures for linear systems of hazardous and other waste]

3. Leachate Management System

47. Leachate is a contaminated liquid that is produced when precipitation percolates through different layers of waste or by degradation of organic matters in an engineered landfill. Other contributors to leachate production can be groundwater and surface water, if not properly diverted or protected. The amount of leachate can be avoided or minimized by covering the surface areas of the waste body which are presently not in operation with temporary membranes or foils, or by using a portable structure that acts as a roof to keep out rain and snow. When appropriate, other systems can be designed to reduce leachate generation during operation.

48. Leachate produced by engineered landfills contains various contaminants at levels that can have an environmental impact on groundwater and surface water quality, as well as pose a threat to the environment and human health. The characteristics of the leachate generated reflect the nature of the waste being disposed of at the engineered landfill. Leachate should be prevented from migrating off site.

49. The environmentally sound management of landfill leachate should be considered an integral part of an engineered landfill location, planning, designing, construction, operation, and maintenance. Landfill leachate requires collection, monitoring and proper treatment throughout the active life, closure, and post-closure of the engineered landfill.

50. A leachate management plan should be developed taking into account the waste type accepted at the engineered landfill and present the leachate system design, the procedures for the pre-treatment and final disposal of leachate collected and also provide for contingency plans, if leachate quality or volume exceeds limits.

51. A leachate management plan for an engineered landfill for other wastes should take into account that hazardous wastes can still be found in wastes collected from households, despite the best efforts to remove them from this stream.

52. An engineered landfill for hazardous waste requires a greater level of effort, sophistication and reliability as well as contingency measures to be incorporated into the plans and design of the leachate control, leak detection and recovery systems. The technology of waste solidification reduces leachate quantity and toxicity, including when liquid waste are not accepted.

53. Before receiving waste, a leak detection should be performed. A leak recovery system (e.g. using electrical sensors or a second drain) should be in place, as it can help to notice damages at the liner system, find the leakage place and estimate the leachate amount. It should where appropriate, 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.

54. Collected leachate should normally be treated before returning to natural environment.

(a) Leachate collection

55. A leachate collection system should be constructed from materials that are resistant to the waste managed in the engineered landfill. It should comprise a drainage blanket, pipework and extraction system. A drainage and collection system for leachate should be maintained within the engineered landfill to allow leachate to be pumped to the surface for treatment prior to discharge. A gravity system is preferable because leachates are extracted without energy and because it ensures the alveolus does not work as a leachate tank.

56. The leachate conveyance system should be constructed using High-Density Polyethylene (HDPE) pipe to withstand the harsh conditions associated with leachate transport. The nature of the leachate (e.g. typically acidic) can reduce the useful life of other pipe materials such as Polyvinyl chloride (PVC), concrete and corrugated metal.

57. The design and operation of a leachate management system should be carefully considered for sites located in cold climates to ensure that freezing conditions do not adversely affect system operation. It should also be designed and operated in a manner that will prevent clogging during all phases of the engineered landfill lifetime. For an engineered landfill equipped with a containment system, the hydraulic head of leachate on the liner should be controlled by a leachate collection system at the base of the waste mass.

58. A hazardous waste leachate collection system should be:

(a) Designed to be functional over the effective lifetime of the leachate generated at the facility;

(b) Designed to be maintained as many times as required;

(c) Constructed of materials that are chemically resistant to the waste disposed of and to leachate and landfill gases generated by the waste;

(d) Have sufficient strength to resist failure due to the pressure of overlying loads (i.e. hazardous waste stabilized in cement, crushed drums or other heavy materials);

(e) Designed and constructed to prevent clogging during the contaminating life span of the facility (including post-closure);

(f) Designed for a storm with a magnitude that is exceeded, on average, once in 25 years and/or for frequent variances in precipitation and temperature caused by climate change.

(b) Leachate treatment

59. A leachate treatment system is required to clean the leachate until meeting the limit values before final discharge. Various leachate treatment technologies are available and the treatment system should be designed by a qualified and experienced professional based on expected contaminant concentrations, expected flow rates, downstream land uses, waterway sensitivity and soil types, among other factors. Off-site and on-site options are available for leachate treatment.

60. A leachate treatment system should have measures in place to prevent and/or contain odours.

4. Surface Water Management System

61. The surface water management system should be designed to collect water falling on the engineered landfill during a storm and control the quantity and quality of the surface water being discharged from the engineered landfill.

62. The clean surface water and collection and conveyance system should be kept separate from the leachate collection and conveyance system.

63. Storm water refers to the water accumulated on the land surface of an engineered landfill site during a rainfall event.

64. The design of external diversion channels, ditches and conveyance structures and design of all lined internal drainage channels, ditches, storm sewers and conveyance structures should be sized to accommodate the peak flow generated by the regional storm event (e.g. the largest storm on record).

65. Storm water falling upon waste or contaminated material should be considered contaminated and treated as leachate. The contaminated runoff generated from the active face and engineered landfill side slopes that await final cover can be captured and conveyed in surface ditching and discharged into the nearest entry point for the leachate collection system.

66. Storm water collected from clean roadways, roofs, vegetated or soil areas free of refuse and areas on which a final cover system has been applied is generally considered clean water and is suitable for discharge without any form of treatment other than sediment control. It should be collected in a retention basin and stored on site for discharge after the peak of the rainfall event has passed.

67. Rainfall which falls upstream of the site but within the same catchment area of the site should be redirected via a cut off trench or ditch located up-gradient of any leachate producing area of the site and directed past the site without coming into contact with any leachate.

68. Before and after storms have passed, the collection and holding systems associated with onsite or off-site control systems should be inspected and quickly emptied or otherwise managed to maintain the design capacity of the water discharges from the engineered landfilling area.

69. Storm water discharge from a site to the receiving water bodies should be limited to a discharge level that is no higher than what would have been experienced before the engineered landfill was developed.

70. For effective run-off control, it is recommended to minimize leachate production by keeping ‘clean water clean’. This can be achieved by:

(a) Diverting clean run-off, by minimizing percolation through the top surface of the engineered landfill and by enhancing run-off;

(b) Preventing erosion of the operational interim and final cover systems and ponding of surface water on the cover system;

(c) Controlling flooding of active engineered landfill areas, to manage suspended sediments, and to control surface water.

71. 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 landfill facility is established, during operation, and following closure;

(b) Design features, control systems and operational procedures to isolate, contain, monitor, convey, control and if necessary treat the storm water (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.

5. Cover system

72. A landfill cover system should minimize the escape of material and gas from the engineered landfill and hinder the forming of leachate because of rain.

73. Two cover systems with different functions should be distinguished: engineered cover (also known as final cover) and interim cover.

(a) Engineered cover

74. An engineered cover should prevent seepage into the engineered landfill and escape of any material or gas. This is achieved by creating an impervious barrier. It should be designed to function with minimum maintenance and withstand predictable events for the duration of the post-closure phase, such as rain, heavy wind, erosion, freeze/thaw cycles, or engineered landfill settlement.

75. A typical engineered cover should consist, from bottom to top, of a compacted cap of clayish materials, a geomembrane liner, a drainage layer and cover topsoil. The mineral layer should have a [maximum conductivity of 1.0 x 10-9 m/s].

76. At the beginning, a selection of vegetation type should be made on the basis of relevant criteria, including but not limited to: climate, activity on the site, sunshine duration, soil quality, availability of water, and future development goals. Later there will be a natural succession.

(b) Interim and daily cover

77. Cover systems should be used if necessary to reduce the risk of fire, contain wind-blown materials, prevent wildlife attraction (i.e. birds, rodents, and insects), reduce odour, and reduce leachate generation. Cover systems also improve drainage, safety, venting isolation, protection of the foundation, and reduces settlement problems.

78. Interim cover should be used for waste isolation or separation or on parts of the engineered landfill temporary not filled. For landfills for other waste, daily cover should be applied.

79. Interim cover should be compacted soil or other environmentally sound materials like geomembranes. It should be adapted to conditions at the engineered landfill, including but not limited to: level of precipitation, presence of vermin, freezing, and location of the engineered landfill cell.

6. Landfill gas management system

80. The decomposition of biodegradable waste under anaerobic conditions produces landfill gas. Landfill gas from engineered landfills for other wastes is typically composed of approximately 50% methane and 50% carbon dioxide, with traces of other compounds, such as nitrogen, oxygen and hydrogen, hydrogen sulfide, and non-methane organic compounds. Methane is a potent greenhouse gas and has a “global warming potential” which is more than 25 times greater than that of carbon dioxide (IPPC, 2014). The NMOC content of the landfill gas contains hazardous air pollutants and volatile organic compounds in varying proportions which may have carcinogenicity and other possible non-cancer health effects (EPA, 1999).

81. The quantities of landfill gas produced and quality depends on the characteristics of the waste (e.g. waste composition and age of the waste) and the environment within the engineered landfill waste (e.g. presence of oxygen in the engineered landfill, moisture content, temperature, stage of decomposition, engineered landfill design and operation (CCME, 2006).

82. Landfill gas may pose environmental, public health and safety issues from the release of chemicals to the air, odours and contribute to fires or explosions (ATSDR, 2001). Therefore, a

landfill gas management system should be established to enable monitoring in order to detect releases of concern and identify mitigation options.

83. Measures should be taken to control the accumulation of landfill gas and mitigate landfill gas emission. These measures may include the collection, treatment and utilisation of landfill gas. A landfill gas management system or program should be designed accordingly.

76. Gas in an engineered landfill for hazardous waste may be generated by the chemical reaction of incompatible waste materials or by the decomposition of organic material. As such, it is recommended to ban the disposal of biodegradable material (including volatile chemical waste) in an engineered landfill for hazardous waste (CCME, 2006)). Another possible source of gas may result from the evaporation of volatile chemical waste.

77. The disposal of biodegradable waste in engineered landfills for other wastes is not recommended in order to prevent or reduce, the production of landfill gas. A number of countries discourage or ban the landfilling of biodegradable wastes so that any future landfill gas generation in the engineered landfill would be minimal or negligible. It should be noted, however, that landfill gas will continue to be formed in an engineered landfill that contains previously landfilled biodegradable waste.

78. Engineered landfills for hazardous waste generally are not expected to generate significant quantities of landfill gas. A monitoring program should be developed to identify the potential for landfill gas production (CCME, 2006).

(a) Gas capture

79. Engineered landfill systems should collect landfill gas with a high gas capture rate before it is emitted. The type of landfill gas collection system required should depend on the type and depth of waste, site conditions, operating status of the engineered landfill and applicable regulations.

80. Measures to contain the landfill gas should include:

(a) Installing impermeable liners on the top, bottom and sides of the engineered landfill to prevent off-site migration and limit infiltration of precipitation;

(b) Install a final cap when the engineered landfill is closed;

(c) Installation of a gas collection system.

81. Landfill gas should be collected through an active collection system. These systems include vertical and horizontal wells, horizontal piping at the surface of the waste to convey the gas, vacuums, valves, pressure gauges, condensers and sampling ports to monitor and control flow

82. Passive gas collection systems may be appropriate if small quantities of gas are produced. These systems use the natural pressure gradient or concentration gradient to vent the landfill gas collected by the wells to a biofilter or incineration system.

83. Landfill gas collection systems should be monitored and adjusted regularly to maximize the capture of gas and minimize the seepage of excessive quantities of air into the waste mass. [Such adjustment can be achieved through an impermeable liner on areas where there is temporarily deposit of waste.]

(b) Treatment

84. Landfill gas that is captured should be treated and utilized (as a source of energy) or, if this is not possible, flared, but not released to the atmosphere. Technical and economic feasibility studies should be undertaken to determine an appropriate utilization technique. In case the quality and the amount of the collected landfill gas is sufficient, it should be utilized to produce energy using techniques such as:

(a) Landfill gas conversion to pipeline quality natural gas;

(b) Direct use of the gas as a stationary or transportation fuel;

(c) Co-generation;

(d) Electricity generation.

7. Cell construction

85. An engineered landfill should be designed and operated utilizing one or more landfill cells, which are spatially separated units within a landfill that can be operated independently. This limits

the exposure of the liner system for portions of the landfill that are not yet in use, and allow sections of the landfill to be closed as they are filled.

8. Monitoring system design

86. Design of an engineered landfill should ensure that all the structural components of the engineered landfill system can be monitored adequately (e.g. leachate, landfill gas extraction, ground water and surface water).

(a) Leachate

87. Target leachate levels should be defined during the engineered landfill design process to achieve design goals. The leachate monitoring locations should be designated during the design process. For engineered landfills with a leachate extraction and drainage system, the monitoring locations should normally be near and downstream of the point where the drains converge and upstream of the leachate treatment system, and immediately downstream of the leachate treatment system.

88. The spacing and location of leachate level monitoring points should be defined during the engineered landfill design process and leachate should be collected at representative points. Sampling and measuring (volume and composition) of leachate should be performed separately at each point at which leachate is discharged from the site. Maximum leachate levels should be defined using a factor of safety that ensures stability of the waste mass. Minimum leachate levels are defined only for engineered landfills where leachate recirculation is implemented.

89. Any leaks or non-compliant ground water test results should be reported immediately.

(b) Landfill gas extraction

90. The spacing extraction wells, or horizontal collectors should be defined during the design process. The spacing and location of landfill gas probes within waste should be also defined during the engineered landfill design process, with probes positioned to confirm performance of the landfill gas management system.

91. For engineered landfills with a landfill gas treatment system, performance monitoring locations for the treatment system should be established during the design process. The monitoring locations should normally be near and downstream of the point where the landfill gas extraction system headers converge and upstream of the landfill gas treatment system, and the system exhaust.

92. [Landfill gas probes installed in soils should be field designed according to the conditions on a given site. The length and depth of screened intervals of probes should be chosen by qualified engineers on the basis of the geology of the site and the most likely pathways for migration of landfill gas.

93. Target landfill gas pressures and in soils surrounding the waste should be defined during the engineered landfill design process to achieve design goals. If performance monitoring indicates that design goals are not met, contingency actions should be implemented.]

(c) Ground water and surface water

94. Background concentrations of analytes in groundwater should be defined during the initial hydrogeologic assessment of the site.

95. All monitoring wells should be:

(a) Installed using best available technology practices;

(b) Isolated within a single hydrostratigraphic unit;

(c) Constructed of materials that are nonreactive to the potential contaminants in the facility;

(d) Constructed with all as-built details recorded locked;

(e) Registered with the jurisdiction of authority upon construction or abandonment (as required);

(f) Locked to prevent malicious acts.

96. Monitoring wells should be installed up gradient (i.e., upstream) of the border line 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.

97. Monitoring wells should also be installed 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 detect any significant contaminants that migrate from the facility.

98. Groundwater monitoring well positions and spacing should be defined during the engineered landfill design process based on interpretations developed during the initial hydrogeologic assessment of the site, and on the site development plan.

99. Surface water level and surface water quality monitoring point(s) should be defined during engineered landfill design. Surface water level and surface water quality monitoring sites should be located based upon the conceptual model of site hydrogeology that was developed during the initial hydrogeologic characterization of the site.

100. Surface water level monitoring points should be established if the surface water body could affect or be affected by groundwater levels, and should be located to allow evaluation of interactions between surface water and ground water. Surface water quality monitoring points should be established if groundwater affected by site operations could discharge to the surface water, and should be located to allow evaluation of surface water quality upstream and downstream of the potential groundwater discharge area.

101. The end use or uses of groundwater and surface water should be identified for each site during initial siting studies including: drinking water, recreational, fresh water aquatic life, agricultural, and industrial. Water quality guidelines should then be established for groundwater and surface water resources and the monitoring system should be designed accordingly to ensure compliance with water quality objectives.

102. The monitoring system should be designed to detect any leakage or release that could lead to contamination of aquatic systems.

V. Environmentally sound operation of engineered landfills

103. Operational costs for engineered landfills may vary between engineered landfills for hazardous waste and engineered landfills for other wastes. These costs may include waste acceptance testing, daily cover, leachate treatment, monitoring, maintenance and repair of infrastructure, operator training, etc. Additional costs should be taken into account if treatment of leachate is performed on site and for satisfying stringent health and safety provisions required for daily operation, especially for engineered landfills for hazardous waste.

A. Waste pre-treatment and acceptance

104. Basic characterization of waste should be done to determine if it can be accepted at the engineered landfill. A list of criteria should be established, including, but not limited to, appearance, composition, source of the waste, and treatment applied. (Note: details on more concrete guidance on waste acceptance criteria are intended to be added at a later stage).

105. Records of the accepted waste should be kept. This should include, at least, the quantity and type of waste, the date of reception, the name of the shipper, and the location in the facility it was redirected to.

106. Acceptance criteria should be specific to every type of facility (i.e., engineered landfills for hazardous waste, engineered landfills for other wastes). Limit values should be established and tested against. Compliance testing should be conducted regularly to verify that the waste complies with the limit values for acceptable waste. On-site verification through visual inspection should be performed on each load of waste delivered to the site. The required documentation should be checked. All testing should be carried out by qualified personnel and proper documentation should be kept and made available to officials on request.

107. The owner of the waste should assess the waste in order to determine if pre-treatment is needed to meet the waste acceptance criteria. Pre-treatment of the waste should be completed before delivery to the engineered landfill, according to the best practices to reduce the quantity of the waste and/or the hazard to human health and the environment. For example, pre-treatment could consist of, but not limited to, blending, chemical stabilization, biological degradation, stabilization/immobilization, incineration, cementation, compaction, evaporation, neutralization, repackaging, and/or filtration/compaction by filter-press.

108. Engineered landfills for hazardous waste should apply the specific acceptance and reception procedures for hazardous waste. They include, but are not limited to:

(a) Full traceability of the waste circuit, from initial waste generator to the engineered landfill, including interim operations/facilities. This can be obtained by means of a notification established by the initial waste producer;

(b) Information on the content and the hazard properties of the waste from the producer.

109. The engineered landfill should be equipped with a laboratory for checking the validity and the consistency of the notification as regards traceability for each waste load and determining the compliance of the waste load with the permit acceptance criteria. In order to do achieve this, a sample should be taken on each incoming waste load and analysed before unloading. If a specific waste load does not comply with the permit acceptance criteria, its unloading should be refused and it should be returned to waste producer.

B. Site activities

110. Waste should be processed (e.g. shredding, compaction or biological degradation) according to the best practices for each waste type. On-site processing should be performed at the most appropriate location, according to the best practices.

111. Noise and dust control measures should be put in place where needed, such as acoustic screens, speed limits, wheel cleaning equipment, and road sweeping equipment. Bird scarers should not be used after dark to reduce irritation to residents.

112. Waste should be sorted and stored in a safe way. Appropriate containers should be used, if applicable, and a storage area engineered to direct runoffs to a storm water management pond.

113. Compaction should be used to reduce the amount of airspace occupied by waste.

114. About 150 mm of cover material should be spread daily, at the end of each day. When an area is expected to be inactive for a longer period (e.g. 6 months), an intermediate cover or impermeable foil should be spread over the waste. Cover material should be cleared or punctured before adding new waste.

C. Leachate treatment

115. Leachate discharged to an outlet channel of an engineered landfill should be treated either on-site or off-site.

1. Off-site Leachate Treatment

116. Leachate generated by engineered landfill for other wastes can be directed to a municipal waste water treatment plant (WWTP) if one is available in close proximity (typically within 5 km).

117. However, it is important to assess if the receiving WWTP is capable of effectively treating the additional contaminant loading from the engineered landfill for other wastes. If the end result at the WWTP is simply dilution of the leachate, on-site treatment should be performed. The treatment of leachate in the WWTP's should only be considered if the peak leachate flow can be appropriately managed.

118. Pre-treatment mechanisms can be considered to improve treatment efficiency and flow of leachate being directed to a WWTP:

(a) A large flow equalization lagoon at the engineered landfill can be used to reduce peak concentration and flows associated with extreme precipitation events and can also provide sedimentation and solids removal;

(b) Pre-treatment of leachate can be achieved in an on-site aeration pond equipped with one or more aerators.

2. On-site Leachate Treatment

119. Leachate generated from engineered landfills for hazardous waste should be treated on-site and treated as a hazardous waste. One treatment method is to use these leachates in the solidification unit of incoming waste, if such a unit is present onsite. If there is no such unit onsite, hazardous waste leachate should be treated by a tertiary treatment process. If the treated leachate is compatible (quality, quantity, physic-chemical characteristics) with the natural environment it may be discharged off-site. If quality or quantity is not compatible, leachates should be treated by a collective hazardous waste treatment plant.

120. The selection of the required leachate treatment method depends on many factors and the final selection should be based on a meticulous procedure which considers all environmental, social and economic aspects specific to each site. On-site treatment methods should also be adaptable to the leachate's evolution over time.

121. Leachate generated by engineered landfills for other wastes far from a WWTP should also be treated on-site before discharging into the environment.

3. Treatment methods

122. The treatment methods are classified in various levels such as primary, advanced primary, secondary (with or without nutrient removal) and tertiary (or advanced) treatment. Many of these treatments are required to be used in combination to effectively treat leachate.

123. The leachate composition and the chemical nature of individual contaminants has a direct impact on their removal efficiencies. While a certain portion of the contaminants can be destroyed by using the treatment methods presented in Table 1, others may simply concentrate contaminants. Therefore, another disposal process will be necessary to permanently destroy these.

124. Combining tertiary treatment methods together with primary or secondary methods may be required for optimal performance, as they can remove a greater proportion of contaminants, including Persistent Organic Pollutants (POPs) and contaminants of emerging concerns (CECs) (e.g. pharmaceuticals and some nanomaterials), significantly improving the quality of water discharged to the receiving environment.

125. The use of tertiary treatment methods in addition to primary and secondary ones can significantly increase the cost of treatment. The treatment objectives should be defined considering the best available technologies that are economically feasible.

Table 1: Typical leachate treatment methods and classifications

Advanced Primary or Secondary	Secondary	Tertiary
Coagulation and Flocculation	Activated Sludge	Microfiltration
Precipitation	Rotating Biological Contactor	Ultrafiltration
Adsorption	Sequencing Batch Reactor	Nanofiltration
Flotation	Reed Beds Wetlands (Constructed and Natural)	Activated carbon absorption
Chemical Oxidation	Biological Aerated Filter	Reverse Osmosis (RO)
Ammonia Stripping	Lagoons (Facultative, Partial-Mix and Complete-Mix aerated)	Artificial/ Constructed wetlands
	Upflow Anaerobic Sludge Blanket	Phytoremediation
	Anaerobic Filter (AF)	Ultraviolet (UV)
	Moving Bed Biofilm Reactor (MBBR)	Photo Fenton Oxidation (UV/O3/Fe2+)
	Membrane Bioreactor (MBR)	

D. Gas treatment

126. Landfill gas that is captured should be treated and utilized (as a source of energy) or, if this is not possible, flared, but not released to the atmosphere. In case the quality and the amount of the collected landfill gas is sufficient, it should be utilized to produce energy using techniques such as: landfill gas conversion to pipeline quality natural gas; direct use of the gas as a stationary or transportation fuel; co-generation and electricity generation. Technical and economic feasibility studies should be undertaken to determine an appropriate utilization technique.

127. Prior to utilization as a fuel, the landfill gas collected from waste should be treated to remove moisture, particulates and chemical compounds, which are abrasive and corrosive in nature. This is necessary to protect landfill gas equipment, reduce maintenance problems and ensure effective

energy conversion of landfill gas. Condensate separated from the gas can be treated, or disposed of in the leachate collection system. Gas treatment systems can include primary and secondary treatment processing; where primary treatment includes de-watering and filtration to remove moisture and particulates, and secondary treatment includes both physical and chemical treatments to remove chemical contaminants such as siloxanes and sulfur compounds. In most cases, the condensate is combined with the leachate for treatment and disposal.

128. Combustion using flares converts methane into carbon dioxide which has a much lower Global Warming Potential. Flares may be used on their own or in combination with an energy utilization system to supplement methane destruction or provide backup. There are generally two types of flares: open flares and enclosed flares.

129. Where landfill gas quality and quantity are not sufficient for flaring and utilization, techniques for biological methane oxidation could be used (e.g., recultivation layer, biofilter, biofilms). This may be suitable where passive venting systems are installed. The performance of this methane oxidation should be controlled periodically at the engineered landfill surface.

130. The destruction efficiency is defined as the quantity of methane collected and oxidized to carbon dioxide through a combustion device or through biological oxidation. The combustion of landfill gas in flares and in utilization should be completed by maximizing the destruction efficiency. Combustion of landfill gas should be monitored to ensure that emission requirements set by the authorities are met.

E. Operation of a monitoring system

131. During the life-span of an engineered landfill, significant changes can take place in practices and in the characteristics of the waste deposited; therefore, continued monitoring ensures that the measures taken remain effective over time. The monitoring system should be in place for all the phases of the engineered landfill life span, including the post-closure phase.

132. Regular monitoring should be undertaken as described within a written Landfill Operation and Maintenance Manual and in the event that the results monitoring show exceedances of specified limits, the actions and /or remedial measures described within a Contingency Plan should be undertaken for all media.

133. Monitoring of the leachate and gas is important for checking the performance of the engineered systems, for determining the nature and interaction of the wastes and may help assess the compatibility of the leachate and gas emissions with the allowed limit values of the facility.

134. Monitoring of settlements and evaluation of stability of the underground and the waste body should also be undertaken regularly.

1. Monitoring parameters

135. Performance monitoring requirements, including monitoring periods (e.g., annual, bi-annual, quarterly, monthly, or seasonal requirements) should be reviewed for each major environmental control system.

136. Generally, for active sites, performance monitoring should take place monthly or more frequently if required under the Operations Plan. For closed sites, performance monitoring should take place quarterly or as defined in the *Post-Closure Monitoring Plan*.

137. All performance monitoring should be performed in accordance with a written *Performance Monitoring Plan*. Each monitoring plan should:

(a) Describe and provide a map showing the installations;

(b) Identify the monitoring devices, instruments, or tools that should be used, including the calibration procedures for each instrument;

(c) Provide detailed instructions for the collection of samples, including collection of quality control or quality assurance samples;

(d) Provide detailed instructions for the collection of measurements, including description of the units of measurement, the required measurement precision and accuracy, and any relevant datum;

(e) Identify all data that should be recorded, including the date and time of all samples or measurements, staff names, weather conditions, sampling locations;

(f) Provide relevant forms or equipment for data recording;

(g) Address health and safety issues by providing or referencing an appropriate *Health and Safety Plan*.

(a) Leachate

138. Landfill leachate is a complex chemical mixture of organic and inorganic compounds produced by a combination of physical, chemical and biological processes. Biological activity within the waste mass is the main factor that influences leachate chemistry. Other factors include the physical and chemical nature of the waste, the extent of waste stabilization (decomposition), and the volume of moisture infiltration into the engineered landfill. Typical contaminants and parameters of landfill leachate are presented in Table 2 and 3.

Table 2: Typical contaminants of landfill leachate

Contaminants Groupings	Contaminants
Nitrogen compounds, phosphate and sulphate	Ammonia and Nitrite/nitrate, phosphorus
Hydrocarbons	Mineral oil, polycyclic aromatic hydrocarbons
Metals, Platinum Group Elements and Lanthanides	Mercury, Methylmercury, Chromium, Nickel, Lead, Cadmium, Boron, Cobalt, Iron, Manganese, Selenium, arsenic, zinc, cooper,
Dissolved solids	Chloride, Calcium, Sodium
Phenol, chlorinated organic compounds and other contaminants of emerging concern (CECs)	Pharmaceuticals and Personal Care Products (PPCPs) Persistent Organic Pollutants (POPs) Polybrominated diphenyl ethers (PBDEs) Hexabromocyclododecane (HBCD) Perfluorinated Compounds (PFCs) Bisphenol A (BPA) Chlorinated alkanes, Siloxanes and Volatile methyl siloxanes Nanomaterials Phthalates Cyanide Pesticides

Table 3: Typical parameters measured in landfill leachate

Parameters of leachate	
Alkalinity (as CaCO3)	Ortho Phosphorus
Ammonia Nitrogen	Potassium
Biochemical Oxygen Demand (BOD5)	pH
Calcium	Sodium
Chemical Oxygen Demand (COD)	Sulfate
Chloride Total Suspended Solids	Total Iron
Conductivity Organic Nitrogen	Total Hardness (as $CaCO_3$)
Magnesium	Total Organic Carbon (TOC)
Nitrate	Total Phosphorus
Organic Nitrogen	Total Suspended Solids

139. Leachate collected from an engineered landfill for hazardous waste should be analysed monthly to monitor hazardous characteristics and parameters, to ensure that it is treated accordingly. For engineered landfill for other waste leachate should be analysed quarterly.

140. Leachate discharge rates should be monitored daily to evaluate leachate extraction and drainage system performance, and supports ongoing treatment system. Leachate infiltration rates and quality should also be measured using lysimeters installed beneath waste.

141. Leachate quality defines the potential risk posed by leachate releases to the environment, allows evaluation of the leachate treatment system performance, and defines changes in leachate quality over time to provide a means of evaluating engineered landfill stabilization.

142. A sufficient number of representative samples of extractable liquids should be taken from the primary and secondary leachate collection systems. If output liquid from the leak detection/secondary leachate collection system should be monitored for flow and physical, chemical and eco-toxicological characteristics. Other equivalent monitoring methods may also be acceptable.

(b) Landfill Gas

143. Landfill gas pressure, flow rate, surface gas and quality measurements are used to define the potential risk posed by releases to the environment, to evaluate performance of the landfill gas control system, to support operation of the landfill gas treatment system and to define changes in landfill gas generation rates and quality over time (these provide a guide to engineered landfill stabilization).

144. Landfill gas pressures, flow rates, surface gas and quality should be monitored monthly. Landfill gas quality monitoring should include monitoring for combustible gas, carbon dioxide, and oxygen, and other constituents such as carbon monoxide, hydrogen sulphide, oxygen, and potentially other constituents. Landfill gas monitoring should also be conducted in the structures on and adjacent to the engineered landfill sites.

(c) Groundwater

145. Groundwater is commonly the initial receptor of released leachate or contaminated storm water due to damage to the liner. Regular monitoring of groundwater is necessary to demonstrate that an engineered landfill is performing as designed and that the impacts on the environment are acceptable. Groundwater levels are monitored to support interpretation of the groundwater monitoring data and should be monitored every six months for level of groundwater and site-specific for the composition.

146. Groundwater quality should meet established water quality criteria by the local jurisdiction. Prior to waste placement, groundwater levels and quality should be measured monthly for at least ten (10) months, or quarterly for at least eight (8) quarters to establish baseline conditions for the site.

147. If quality control limits downgradient of the engineered landfill are exceeded, or increasing trends of one or more parameters downgradient of the engineered landfill are identified, or a parameter not present in background groundwater is detected downgradient of the engineered landfill for three consecutive quarters, contingencies actions should be implemented.

148. An effective monitoring program should be based on a sound understanding of the groundwater flow system in the area and potential contaminant migration.

149. Indicator parameters should be determined to assess the degree of contaminant migration once landfilling has begun operation however, as precautionary measure a full characterization of ground water quality should be completed annually.

(d) Surface Water

150. Surface water levels support data interpretation and allow comparison of surface water levels with groundwater levels. Surface water quality data provide performance monitoring for the engineered landfill. It should be monitored quarterly.

151. Surface water quality should meet established water quality criteria, as defined in appropriate water quality guidance for the local jurisdiction.

152. Water quality of one or more parameters should not display an increasing trend, water quality parameters should not exceed the corresponding quality control limit and any parameter which is not present in the background surface water should not be detected in three consecutive sampling events.

(e) Non-Contact Surface water

153. Regular monitoring of surface water is necessary to demonstrate that an engineered landfill for hazardous waste facility is performing as designed and that the impacts on the environment are acceptable. Sampling should be done quarterly, as well as for specific storm events and should meet established water quality criteria by the local jurisdiction.

154. Non-contact storm water quality should be monitored at sites where detention and/or polishing facilities are constructed to provide performance monitoring of these facilities.

155. Acceptable concentrations of analytes in non-contact storm water should be defined during the site permitting process and based on the quality of the receiving surface water system.

156. For active sites, non-contact storm water quality should be monitored after the first major storm during the fall, and after threshold events as required under the Operations Plan. Periodicity should be determined on a site-specific basis.

157. Discharges from on-site surface water control facilities should be monitored together with the potential effects on bodies of water that receive these discharges.

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

(f) Ambient Air Quality

159. Ambient air should be monitored at active sites for combustible gases, carbon dioxide and, if appropriate non-methane organic compounds (NMOCs) within building foundations, within buildings, and at other strategic locations around the site.

160. Ambient air is monitored to evaluate the quality of air that site workers breathe, and to evaluate whether combustible concentrations of gases have accumulated within buildings or their foundations. Air quality standards for air that workers breathe, and for explosion and combustion hazards, should be defined in the Operations Plan.

161. Air emission performance monitoring 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 H2S and CH4 or less common compounds such as HCN or H2. The potential for gas generation exists over the lifespan of the hazardous wastes.

2. Reporting of monitoring results

162. Any exceedance of limit values should be reported to the responsible authority according to relevant jurisdictions and regulations. All performance monitoring should be reported to the responsible authority annually. Report contents should be defined in the Operations Plan. In general, performance monitoring reports should:

(a) Describe and provide a map showing the installations;

(b) Describe any site work or activities that could affect monitoring results or the interpretation of results (e.g., replacement of a monitoring well, or modifications to landfill gas extraction system operations);

(c) Present a tabular summary of any exceedances;

(d) Provide a written discussion of any exceedances;

(e) Identify the monitoring devices, instruments, or tools that were used;

(f) Describe any deviations from the Performance Monitoring Work Plan(s);

(g) Present tabular, graphic, and written summaries of the data collected during the monitoring period;

(h) Present comparisons of results for the monitoring period with results from the period of record, including comparisons using appropriate statistical and trend analyses.

163. Biomonitoring may be required if human receptors have been exposed to contaminants from an engineered landfill, as well as monitoring of potentially impacted wildlife and fish.

164. The annual report should contain the results of the leachate monitoring measurements, an assessment of these results, the corrective actions taken in response, and the relative success of the corrective actions. The assessment of the results for groundwater monitoring, surface water monitoring and air emissions should also be included in an annual report. The annual report should be prepared by a qualified professional and submitted within a reasonable period of time.

165. If a report is submitted containing a notification of a deviation of results for all media (groundwater, surface water or air emissions) 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 responsible authority a specific plan that describes any assessment or corrective action.

3. General Inspection

166. Physical inspections of the engineered landfill for hazardous waste 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.

167. Special inspections should be performed following damages at the facility, exceedances of limit values or other critical situations.

4. Contingency Planning and Implementation of Contingency Plans

168. A Contingency Plan should be prepared that defines:

(a) Action (trigger) levels for each medium for which performance monitoring is performed;

(b) Communications that should ensue if performance monitoring indicates that an action level has been equalled or exceeded;

(c) Follow-up actions and communications that should be performed to confirm the accuracy and precision of the original measurement;

(d) Remedial or corrective actions that should be performed until performance monitoring confirms compliance with the original actions levels.

169. Emergency contact information, including names, responsibilities, and contact details (telephone numbers, email address, and/or mailing address) for critical personnel should be clearly identified at the front of the plan; these data should be confirmed annually and updated whenever changes are confirmed.

170. The Contingency Plan should be updated concurrent with Operations Plan updates.

F. Transportation

171. Transportation of wastes should be done in a safe and secure manner, and respect local regulations and requirements. Additional care should be taken when transporting hazardous waste, and any accidental spills of hazardous liquids should be cleaned.

172. Containers should be properly labelled, and include at least the name and address of shipper, name and address of receiver, quantity and type of waste being transported, and safety warnings.

173. Liability insurance should be contracted by the shipper, and minimum amounts should be set by the regulator according to the type of wastes being transported and socio-economic considerations.

174. Staff involved in the transportation of wastes should be properly trained, and a waste transporter permit should be required. Training should at least provide staff with information on the wastes being transported, how to deal efficiently with emergencies, and understanding of the local regulations and requirements.

175. Documentation on the transportation of wastes should be kept by local authorities.

G. Record keeping and reporting

176. Records should be kept throughout all phases of the engineered landfill lifespan, including post-closure. These records should be readily available and respect all relevant regulations and guidance. Copies of the records should be kept in a way to prevent their loss in the event of an accident.

177. Records of all the accidents, incidents and near misses on the site should be kept, including catastrophic ones and their identified causes.

178. Records of the activities on the site should be kept, including but not limited to:

(a) Type and quantity of waste being landfilled;

(b) Movements of waste from acceptance to landfilling;

(c) Parameters analysis of waste samples at the time of acceptance;

(d) Pre-treatments and/or treatments of wastes;

(e) Maintenance, construction or improvement activities;

(f) Staff responsible for each task on the site on a specific date;

(g) Equipment used;

(h) Equipment failure;

(i) Monitoring parameters and the results of the monitoring tests;

(j) Visitors and inspections;

(k) Weather conditions;

(l) Closure of cells;

(m) Miscellaneous.

179. Financial records should be kept according to the regulations and best practices. Audits should be performed on a regular basis.

180. Reports should be made on a frequent basis to the competent authorities on the activities at the engineered landfill. Moreover, public participation should be encouraged, therefore reports should be made available to the general public and contain information sufficient both quantitatively and qualitatively to ensure a good understanding of the activities at the site. Comments by the different stakeholders on the reports should be taken into account in the improvement process of the reporting obligations.

181. Different versions of relevant operational documents should be controlled to make sure that only the most up to date one is in circulation.

H. Health and safety

182. All equipment and procedures on the engineered landfill site should comply with local health and safety regulations and guidance.

183. Access to the engineered landfill site should be controlled.

184. Staff should be made aware as soon as possible of new conditions on the engineered landfill site, for example but not limited to, location of hazardous materials, presence of visitors, presence of new staff, presence of new equipment, and changes of procedures.

185. Staff should be trained to recognize dangerous materials and deal with them in a safe and secure manner. When dangerous materials are discovered, staff should notify the authorities, if appropriate (i.e. if dangerous materials are suspected to have been illegally introduced to the site.

186. Staff should wear appropriate safety gear, such as safety boots, gloves, hard hats, and easily visible safety clothes. Moreover, appropriate clothing for the weather conditions should be worn.

187. Activity on the site should be restricted when conditions pose a workplace hazard (i.e. heavy rain, low light conditions, or extreme weather).

188. Heavy machinery, such as bulldozer, should be driven in a manner to avoid tipping, for example, driving across the side slopes. Moreover, drivers on the site should undergo training on environmentally sound driving, including health and safety hazards.

189. Staff should undergo training on fire management techniques.

190. The landfill’s safety operations manual and emergency manual should be easily available for all staff to consult at any time. Moreover, staff should undergo mandatory training on safety and emergency procedures on a regular basis.

191. A periodic review of all the equipment and procedures in use should be undertaken. This periodic review should identify strengths and weaknesses and provide advice on ways to improve.

192. Any health and safety incident, accident or near miss should be reported and carefully recorded. Lessons should be learned from these events and health and safety procedures updated accordingly.

193. An employee wellness program should be in place and improved on a regular basis.

VI. Closure and Post-Closure

194. The information contained in the following paragraphs applies to different scenarios; progressive closure of an engineered landfill cell, and decommissioning of an entire facility.

195. Monitoring of the closed cell(s) should be maintained through the closure process and post-closure. Environmental monitoring should include characterization of surface water, groundwater, leachate and landfill gas in and around the engineered landfill. Moreover, soil testing for contamination should be carried out, especially where hazardous wastes were processed and stored.

Monitoring by experts should guide the decisions on the leachate and landfill gas management systems during the post-closure phase (i.e. the length of time these systems should be maintained).

196. Any contaminated soil in an unlined storage area should be removed and treated according to the best practices.

197. In general, closure phase of a cell or facility should begin at the latest 30 days after the reception of the final wastes and be completed within half a year, weather-permitting.

198. The closure and post-closure activities of engineered landfills that are not environmentally sound are outside the scope of these guidelines.

A. Closure

199. A closure plan should be prepared during the design of the engineered landfill. This plan should be updated to reflect the current conditions on the site from the design phase to closure phase. A closure plan should cover the aspects listed in paragraphs 208 to 213 (EPA, 2016).

200. Temporary cover should be placed on closed sub-sections of the cell. This practice should reduce the volume of contaminants (i.e. leachate) produced at the engineered landfill site.

201. Expected landfill settlement should be taken into account when planning closure of a cell.

202. A final cover system of one or more impermeable layers, a drainage layer and a recultivation layer should be put in place over a closed cell. A landfill gas management system, if appropriate, should be maintained as gas can accumulate under the final cover system. An alternative cover system could be used if its environmental performance is evaluated to be equivalent by experts.

203. The monitoring system should be adapted for the post closure phase.

204. Appropriate plant species should be selected for vegetation coverage. This selection should be made on the basis of species tolerance to contaminants, climate, activity on the site, sunshine duration, soil quality, availability of water and other criteria specific to the engineered landfill cell. Damage to the vegetation cover should be reduced by limiting vehicle traffic and by maintaining landfill gas management systems, where appropriate.

205. Infrastructure and equipment should be decommissioned when they are no longer needed for the operations of the site. Every effort should be made to reuse any equipment, when applicable.

206. Closure reserves should be kept and reviewed on an annual basis to ensure sufficient funding during closure phase. The closure fund should be established during the design phase of the engineered landfill and structured to accumulate interest on the deposits over time. The level of funding necessary for closure should be established by a team of finance and engineering experts.

207. Records of all relevant information should be kept to guide future development of the site. These records should include, at least:

(a) Dates of operation;

(b) Design characteristics of the cells and facility;

(c) Types of waste;

(d) Location of the engineered landfill cells and other components of the facility.

B. Post closure

208. A post-closure plan should be prepared during the design of the engineered landfill. This plan should be updated to reflect the current conditions on the site from the design phase to post-closure phase and take into account future land use goals.

209. During the post closure phase the leachate collection and cleaning system and the landfill gas extraction system should be operated and maintained as long as necessary. The behaviour of the engineered landfill should be monitored until the end of this phase.

210. Future land use goals should be considered in any decision throughout the post-closure phase.

211. Vegetation should be monitored throughout the post-closure phase for any damage. Landfill settlement, soil stability and erosion should also be monitored.

212. Post-closure reserves should be kept and reviewed on an annual basis to ensure sufficient funding during post-closure phase. The post-closure fund should be established during the design phase of the engineered landfill and structured to accumulate interest on the deposits over time. The

level of funding necessary for post-closure should be established by a team of finance and engineering experts.

213. Post-closure care should be ended when monitoring by experts confirms that effective contaminating lifespan is over. The minimum post-closure care is usually 30 years, but this varies on a site-by-site basis. Moreover, engineered landfill settlement, soil quality, water quality, and air quality should be considered before the authorization of any new development of the site.

VII. Emergency response

214. An emergency response plan should be made available to all staff. Moreover, staff should undergo training on a regular basis. This response plan should include, at least:

(a) Relevant legislation;

(b) Managers responsible, accountable and who have the authority in emergency response situations;

(c) Duties of personnel;

(d) Map of the facility, including location of critical infrastructure;

(e) Available emergency equipment and location;

(f) General procedures for emergency response;

(g) Fire prevention measures;

(h) Measures to prevent and contain explosions;

(i) Firefighting measures;

(j) Medical emergency measures;

(k) Environmental emergency measures (i.e. unacceptable leachate or biogas leaks);

(l) Spill containment measures;

(m) Geotechnical instability measures;

(n) Measures to prevent and deal with accidents involving vehicles;

(o) Training;

(o) Procedures for emergencies.

215. Liability insurance should be contracted. The amount should be determined on the basis of local regulations and guidance and take into account various criteria, including but not limited to the type and quantity of wastes, activities on the site, location of the site, design of the site, and tolerance to financial risk.

VIII. Public participation

216. Public participation should be encouraged in all the phases of the engineered landfill lifespan. Public outreach, meaningful consultation and engagement and open dialogue are important because they build the different stakeholders' appreciation of the needs and concerns of the community as a whole. Moreover, over the years this can lead to strong partnerships that help in problem-solving by reducing miscommunication issues and lead to better decision-making for all the stakeholders involved.

217. Public participation should be encouraged as soon as the design phase of the engineered landfill. Communities should be involved in the choice of the location of a site as this could greatly reduce frictions and the chances of making a poor decision.

218. The different stakeholders should meet on a regular basis to express their needs and concerns during the active operations phase of the engineered landfill. This can lead to the identification of issues before they become a major problem and thus lead to better management of the engineered landfill, according to environmental, social and economic criteria.

219. Vigilance should be maintained during the closure and post-closure phases of the engineered landfill. Public participation can help identify new issues, and also bring to light useful information for achieving future development goals that benefit the community as a whole.

220. A communications plan should be made and updated on a regular basis. This plan should aim to keep all stakeholders informed of new information as soon as possible and should value a transparent and direct communications approach.

Annex I to the technical guidelines

[Still under development - Parties are invited to submit examples of national legislative and regulatory frameworks]

Examples of national legislation and regulatory frameworks related to engineered landfills

Country	Legislation and link	Brief description
Canada	https://www.ontario.ca/laws/regulation/980232 http://legisquebec.gouv.qc.ca/en/showdoc/cr/Q-2,%20r.%2013/20120901 https://www2.gov.bc.ca/assets/gov/environment/waste-management/garbage/landfill_criteria.pdf	Regulations related to landfill design, operation, monitoring, and closure for Ontario, Quebec, and British Columbia
European Union	Council Directive 1999/31/EC on the landfill of waste https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=LEGISSUM:l21208&from=DE	The objective of the Directive is to prevent or reduce as far as possible negative effects on the environment, in particular on surface water, groundwater, soil, air, and on human health from the landfilling of waste by introducing stringent technical requirements for waste and landfills. The Landfill Directive defines the different categories of waste (municipal waste, hazardous waste, non-hazardous waste and inert waste) and applies to all landfills, defined as waste disposal sites for the deposit of waste onto or into land. Landfills are divided into three classes: • landfills for hazardous waste; • landfills for non-hazardous waste; • landfills for inert waste. The Directive describes site selection criteria, technical construction and operational requirements for the different types of landfills.
European Union	Council Decision 2003/33/EC of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=LEGISSUM:l21208&from=DE	The Council Decision introduces a multi-step assessment of wastes to be landfilled (basic characterisation – compliance testing – on-site verification. The Decision also introduces leachate criteria.
Germany	Landfill Ordinance http://www.gesetze-im-internet.de/depv_2009/DepV.pdf	To be added

Annex II to the technical guidelines

[Still under development]

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