BASEL CONVENTION TECHNICAL GUIDELINES ON SPECIALLY ENGINEERED LANDFILL

Basel Convention on the Control of Transboundary Movements on Hazardous Wastes and Their Disposal

No. 3

UNEP

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ON THE CONTROL OF TRANSBOUNDARY MOVEMENTS OF
HAZARDOUS WASTES AND THEIR DISPOSAL

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SECRETARIAT

TECHNICAL GUIDELINES ON SPECIALLY ENGINEERED LANDFILL (D5)

Revised Version
These Technical Guidelines were prepared by the
Technical Working Group of the Basel Convention and
adopted by the third meeting of the Conference of the Parties
to the Basel Convention in September 1995, Geneva

Basel Convention
Technical Guidelines on Specially Engineered Landfill (D5)

Basel Convention series/SBC No. 02/03
First Published in 1997 and
reprinted in November 2002

Sales No. E.02.III.D.203

ISBN : 92-1-158603-8

ISSN : 1020-8364

Printed in chlorine-free cyclus paper

This Publication is available from:

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Foreword

These technical guidelines are principally meant to provide guidance to countries who are building their capacity to manage waste in an environmentally sound and efficient way and in their development of detailed procedures or waste management plan or strategy. They should not be used in isolation by the competent authorities for consenting to or rejecting a transboundary movement of hazardous waste, as they are not sufficiently comprehensive for environmentally sound management of hazardous waste and other waste as defined by the Basel Convention. These technical guidelines concern waste generated nationally and disposed of at the national level as well as waste imported as a result of a transboundary movement, or arising from the treatment of imported wastes.

It is necessary to consider this document in conjunction with the Document on Guidance in developing national and/or regional strategies for the environmentally sound management of hazardous wastes (SBC Publication - Basel Convention Highlights No. 96/001 - December 1995) adopted by the second meeting of the Conference of the Parties. In particular, special attention should be given to the national/domestic legal framework and the responsibilities of the competent authorities.

These guidelines are meant to assist countries in their efforts to ensure, as far as practicable, the environmentally sound management of the wastes subject to the Basel Convention within the national territory and are not intended to promote transboundary movements of such wastes.

CONTENTS

INTRODUCTION

1. These technical guidelines provide general guidance on specially engineered landfills used for the wastes which exhibit one or more hazardous characteristics. The technical guidelines also discuss the landfilling of other wastes, as defined in the Basel Convention, e.g. collected from households, to provide a more comprehensive picture on environmental and health problems arising from landfills. In addition to the requirements for establishing new landfills, the technical guidelines also consider the critical issue of existing or abandoned landfill sites which require strict control, monitoring and often remedial measures. They provide general guidance as to which hazardous wastes would be suitable for landfilling.

2. Landfill is by far the most commonly practised waste disposal method in the majority of countries. It is the descriptor used for the placement of wastes into or onto the ground and, in many cases because of the nature of the materials involved, equates to long-term storage.

3. As a result of serious environmental and health problems experienced with historic and abandoned dump sites and the very high costs associated with clean-up measures at contaminated sites, many countries have introduced the "specially engineered landfill concept", the wastes for which are only consigned to sites selected for their containment properties, these being natural, augmented by or provided directly by liners, the overall engineering being such as to ensure as far as possible the isolation of wastes from the environment. Such landfills are considered a final resort option only to be used after every effort has been made to reduce, mitigate or eliminate the hazards posed by such wastes.

4. Reducing dependence on land disposal through waste prevention, minimization and other technical possibilities represents the first choice in the hierarchy of hazardous waste management options. Chapter 20 of UNCED Agenda 21 stipulates that prevention of the generation of hazardous wastes and the rehabilitation of contaminated sites are the key elements for environmentally sound management, and both require knowledge, experienced people, facilities, financial resources and technical scientific capacities. In this regard a precautionary approach should be applied to landfill disposal. Such approach could be summarized as follows:

> Environmental protection should be undertaken whereby preventive measures are taken when there is reason to believe that substances, waste or energy introduced into the environment are likely to cause harm even when there is no conclusive evidence to prove a causal relation between inputs and their effects.

5. While waste avoidance is clearly the preferred management option, current patterns of waste generation mean that landfill, as a disposal method will continue to be used. Many countries are faced with starting a hazardous waste management programme with the existence of unregulated dumping sites. They need in this case to focus on immediate remedial measures and improvements where these sites are continuing to operate as well as considering waste management strategies which should be based on the concept of providing long-term security rather than short-term expediency which is inappropriate in respect of the landfilling of wastes.

6. Short-term actions must commence with a thorough site investigation and assessment of environmental impacts, the monitoring and reporting of wastes received and any problems caused by unregulated disposal. Some control must be exercised at dumping sites while simultaneously attempts are to be made to upgrade the site.

7. Existing and ongoing landfills, where a significant proportion of biodegradable or bioconvertible materials is contained in the wastes deposited, will benefit from improved controls over the moisture content, pH, compaction/density. These will allow for improvement in the chemical and biochemical degradation of the wastes leading to a more rapid stabilization of the mass. The tendency is to increase pre-treatment processes prior to landfilling. Useful technologies which are increasingly used are solidification and chemical fixation. Very soon after (or even better, simultaneously) there should be an attempt to go back to the source of the wastes to see if some reductions cannot be made there. For many wastes where there is no satisfactory disposal option, source reduction provides the most viable management action, this being especially the case in small countries. In a number of countries, landfill disposal is likely to be the only method available for the disposal of significant quantities of hazardous wastes.

Types of Landfill

8. Generally three situations are experienced in practice:

- *Historic, closed sites*: The management of any problems associated with these will be influenced by the level of knowledge regarding inputs, past experience, when the site was closed, those post the early 1960's having greater problem potential, and what restoration and aftercare measures, if any, were installed.

- *Historic, still operating*: Here how problems can be most effectively managed will be influenced by such factors as the level of knowledge in respect of previous inputs, when licensing/authorization systems providing for improved controls and improved management regimes were put in place, pre or post the early 1960s, changes in the nature of inputs, etc.

- *Green Field sites*: These are set up according to waste being handled and will be the subject of appropriate license/authorization conditions, which produce where appropriate for phased restoration, and operated under quality assured management regimes should present minimal operational, restoration and aftercare problems.

Specific Operational Types of Landfill

9. *Containment sites*. These include those affording material containment are frequently found in naturally occurring clay deposits, involving the filling of the void spaces created by the extraction of clay for brick making or cement manufacturing and those with engineered liners augmenting or substituting for natural containment. In both these cases it is also common to install liquid collection systems below and above the liners so that any leachate which leaks through or is retained on them can be recovered.

10. *Those providing for attenuated release.* Here the underlying natural or artificially engineered strata provides an unsaturated zone which allows for physical, chemical and biochemical attenuated release processes to occur, the result of these minimizing the pollution potential of any leachate and allowing the capacity of the recipient environment to accommodate any released species not to be exceeded. There are parallels here with the recipient-environments ability to accommodate the fluxes of material arising for the weathering and exposure to water flow of naturally occurring minerals.

11. In the context of this paper a specially engineered landfill is seen as one customary providing for containment; having such features as installed drainage to recover any leakage, providing for leachate management including recirculation and gas control systems where appropriate, Also almost certainly operating on a cell system employing progressive restoration. Successful containment is achieved through (a) the selection of a suitable site, (b) high standards of operation and (c) a strict selection and/or pre-treatment of the wastes to guarantee (by way of their chemical properties) a long term minimization of releases into the environment.

Specially Engineered Landfill

12. This form of landfill however, which provides the means for the controlled deposit of wastes on land is sometimes the only practicable disposal option for wastes, in particular for hazardous wastes. In principle, and for a defined time period, a landfill site can be engineered to be environmentally safe subject to appropriate siting, proper precautions and efficient management. Preparation, management and control of the landfill must be of the highest standard to minimize the risks to human health and the environment. Such preparation, management and control procedures should apply equally to the process of site selection, design and construction, operation and monitoring, closure and post closure care.

Operational Methods

13. There are a number of different ways of depositing hazardous waste in a landfill. Each has advantages and disadvantages.

14. Any landfilling of hazardous waste poses a potential threat to human health and the environment, and must therefore be undertaken with great care. A high level of technical competence is required in designing, operating and monitoring the site.

15. Wherever possible, hazardous wastes should be pre-treated to render them less hazardous or inert before landfilling. Many pre-treatment possibilities are available, but a discussion of them is beyond the scope of this paper. Widely used pre-treatment operations are, in particular, incineration and physico-chemical processes.

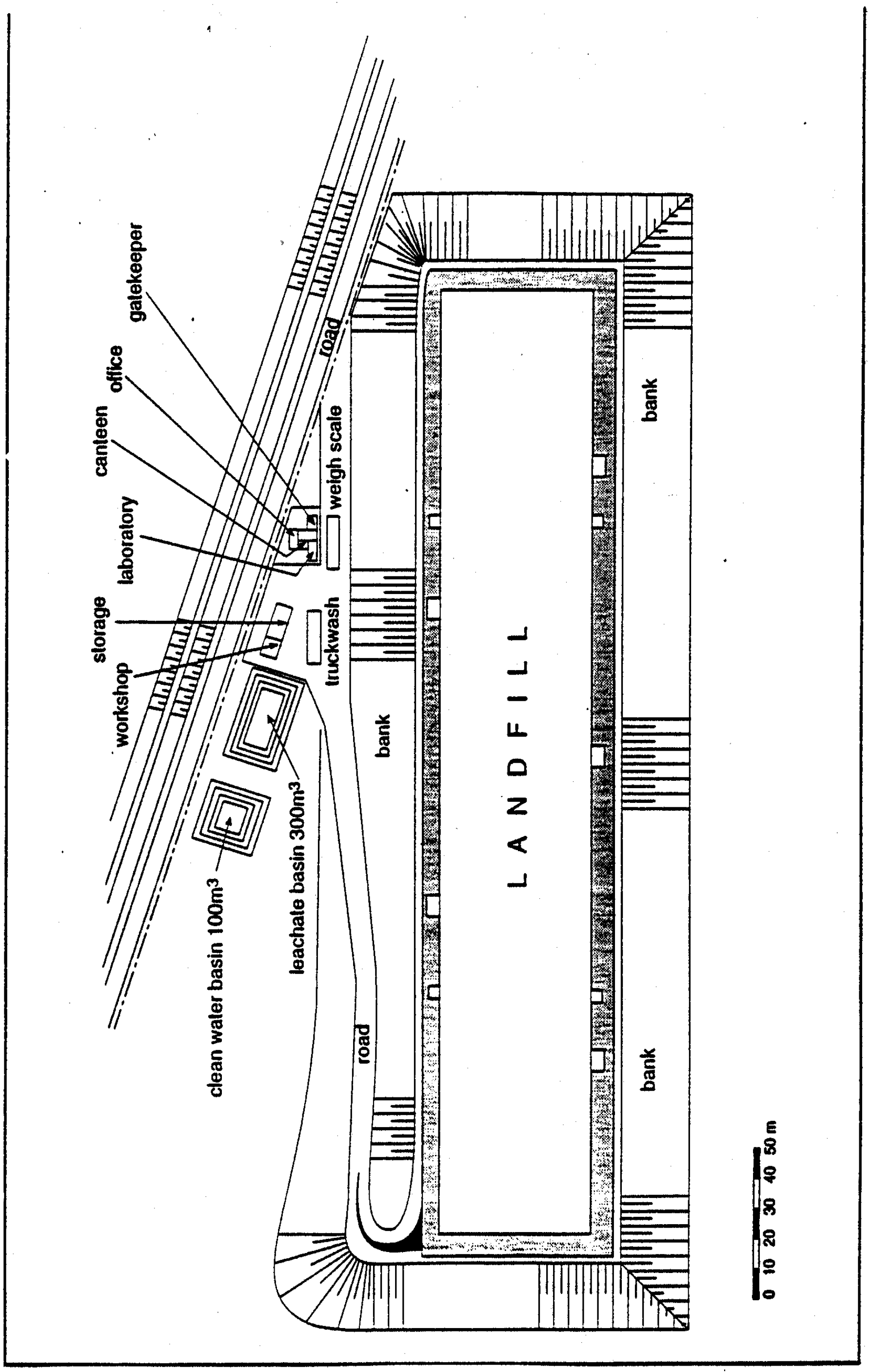
16. Two specific ways of landfilling hazardous waste are mono-disposal and co-disposal:

- *Mono disposal* means placing a single waste stream (or closely-related streams) either in a landfill or in an individual cell in a landfill. For non-degradable wastes this is, in effect, permanent storage. For this reason, close attention must be paid to the long-term engineering stability of the site, and to precautions to be taken against the site being accidentally breached. The consequences of any release must be evaluated.

- *Co-disposal* uses the processes of degradation of municipal waste to destroy or stabilize hazardous waste. Eventually, after many decades, such a site can become stable and operate as permanent storage. However, the reactions involved are complex and not well understood. For this reason only wastes which are amenable to destruction in this way should be co-disposed, and comprehensive monitoring of emissions from the site should be undertaken during its active period.

17. It is strongly recommended that different wastes should not be mixed in a landfill site unless some significant reduction in hazard is expected to result from their mutual interaction. Even then, any such mixing should be carried out in a controlled and monitored way.

Figure 1 LANDFILL SITE LAY-OUT (Taken from UNEP Industry and Environment Technical Report 17)



Environmental and Human Health Aspects

18. In assessing the risks associated with landfill activities the landfill needs to be characterized in terms of the factors which will affect the degree to which human exposure may occur. In this regard, an immediate and long-term environmental impact assessment has to be carried out as required under national legislations or procedures. The environmental impact assessment which is applied to "specially engineered landfill" should cover scoping, objectives and policy making, assessment of baseline status, identification, prediction and evaluation of impacts on major and sensitive components of the environment. Issues like long-term impacts, after-care management and long-term land use policies should be considered. In characterizing the landfill, three important areas can be identified:

- Wastes involved; what type of wastes have been or are being deposited and in what quantities and forms? What are the disposal methods employed? Also, any new waste coming into the landfill should be sampled and analysed.

- Chemicals involved; what chemicals are present in the wastes and in what form and concentration do they occur? Subsurface conditions; what type of materials are present below the landfill?

- Control systems; for instance what type of cover exists over the landfill, and what types of leachate and surface run off controls are present.

Chemicals

19. Typically, a large number of chemicals will be present within a landfill. Unless specific sampling has been carried out on the contaminated materials, it will be very difficult to determine exactly which chemicals are present and in what concentrations they occur. In order to provide analysis for sites where no sampling has been done, it is necessary to outline groups of indicator chemicals associated with different waste streams. A procedure can be used with estimation of the annual amounts of different types of wastes deposited at the landfill and the landfill volume utilized to provide approximations of selected indicator chemicals in the waste. This procedure must be modified to account for the disposal of drummed and liquid wastes which may or may not be restricted to portions of the landfill area. In the case of landfills that are still operating, a sampling and analytical programme should be carried out for any incoming wastes.

Subsurface and surface conditions

20. At many landfills no leachate controls were implemented during landfill construction. In these cases therefore the subsurface conditions have to be generally defined by the local geology and soil characteristics. Where liners and leachate control systems were in place, they can be effective in preventing ground water contamination. Most landfills are covered with a temporary cover during operation, and final soil or clay cover prior to closure or abandonment. The presence of a clean cover over the waste can reduce exposures via wind-born dusts, erosion of the contaminated deposit by surface run off, and by direct contact to persons using the site. The cover may or may not be vegetated and maintained, factors which will have an effect on the overall efficacy of the cover.

On-site and Off-site Exposure

21. In order for contaminants residing in a landfill to have an impact on human health, there must exist the potential for the chemical to come into contact with individuals. This contact can occur either as on-site exposures as a result of the receptor entering the landfill itself, or as off-site exposures as a result of chemicals migrating from the landfill to off site exposure points.

Potential Exposure Pathways

22. The link between chemicals in the landfill and the potential receptors constitutes an exposure pathway. There are three essential components of a pathway which must be present for the pathway to complete:

- A chemical release mechanism;
- A transport route for chemicals to migrate to an exposure point;
- An exposure point, where human or environmental exposures may occur.

23. The nature of a chemical release depends heavily on the form and conditions in which the chemicals exist in the landfill. Release mechanisms are different for liquids in containers losing their integrity than for chemicals bound to soil particles by adsorption, dissolved with residual soil moisture, or present in perched ground water within the landfill. Many waste sites are characterized as having contaminated soil areas where chemicals previously released in liquid form are adsorbed onto the soils and are released slowly by leaching. A surface impoundment containing contaminated liquids might release chemicals through volatilization into the atmosphere and by infiltration of the contaminated liquids through the unsaturated soil zone.

24. Often, on-site exposures are not the most significant hazards associated with a site, since site access is usually restricted to a point where exposures are rather infrequent. Once the release of chemicals has been evaluated, the next step is to examine their transport to points where more substantial evaluating chemical movement through several media including transport routes if dependent on both release mechanisms and exposure points of concern. Exposure points may be identified as points where individuals would indicate the likelihood for future contact. Common exposure points evaluated at waste disposal sites include nearby water supply wells, points of discharge of ground water to surface water, local surface water used recreationally or as drinking water supplies or as a source of fish, and property boundaries or nearest residences where the population may be exposed to air borne contaminants.

25. There are many pathways by which exposure to wastes in landfill can occur. Experience with site-specific risk assessments based on exhaustive site investigations in the USA has shown that it is common to find upwards of 95% of the exposure associated with a particular site attributable to one exposure pathway. Identification of applicable exposure pathways begins with the identification of possible release mechanisms for wastes contained in the landfill. These include:

- Leachate production; chemicals may leach from soils and wastes contained in the landfill and be carried out of the contaminated area via percolating water;

- Contaminated surface runoff; chemicals may leach from soils and wastes and be carried by surface runoff. Surface runoff may also carry contaminated soils as suspended particulates;

- Gas production; gases produced within the landfill may migrate due to pressure gradients carrying volatile chemicals outside the contaminated area;

- Volatilization; volatile chemicals may be given off directly into the atmosphere;

- Dust emissions; wind-borne particulates may carry absorbed chemicals.

Persons who come into direct contact with the landfill may carry away contaminated material on their skin and clothes.

26. At most landfills it is also best to avoid the deposition of significant quantities of soluble materials that are not, or are only slowly bioconvertible. Similarly, the deposition of chelating agents that can solubilize heavy metals should be avoided. It is also important to minimize the amount of organo-chemical wastes entering into the landfill.

SAFE LANDFILL MANAGEMENT PRACTICES

1. *General considerations*

27. Landfill operations should be part of an integrated overall system of waste management which include the steps involved in a "cradle to grave" and "after disposal care" approach. Residuals from treatment process or disposal operations that are not discharged as treated effluent or emissions to the environmental media and which are still hazardous are deposited in a specially engineered landfill. All landfill operations require careful planning in advance of the first deposit of waste. How a landfill is operated determines to a large extent the environmental effects. One basic factor influencing the planning of site operations is the nature and quantity of incoming waste. Figure 1 provides for a typical operational plan for landfill site (from U.K. Dept. of the Environment, Waste Management Paper No. 26).

28. The major disadvantages of landfill disposal include:

- The potential risks for polluting water resources;
- The potential risks of contaminating the soil;
- The generation of landfill gas i.e. methane and carbon dioxide;
- Potential human exposure to volatile chemicals;
- Smell, vermin and fire;
- Destruction of natural/virgin sites;
- Long term and cost intensive clean-ups remediation and monitoring (aftercare, close-up).

Landfill has several advantages:

- Landfill can represent a long-term storage method;

- It is not an unduly capital-intensive disposal method over time although setting up costs could be high;
- It is widely available;
- It is comparatively insensitive to day-to-day variations in the quantity and nature of the wastes deposited;
- It is appropriate in a wide range of circumstances (i.e: equipment, technology and skills are available virtually worldwide at local levels).

29. Proper site selection, design of the landfill, control and management of operations, control of input waste, installation of appropriate means for avoiding leachate outside the fill and reducing escape of landfill gas would be necessary to minimize the potential harmful effects of a land filling on public health and the environment and minimization of free[1] liquids placed in the landfill as well as minimization of precipitation and run-on into the fills is achieved.

30. As stated earlier, specially engineered landfills could be used as a disposal option for selected hazardous wastes provided adequate safety measures including pre-treatment of the waste in question are being taken to protect human health and the environment, and minimization of free liquids placed in the landfill as well as minimization of precipitation and run-on into the fills is achieved. There are, however, a number of hazardous wastes for which landfill disposal is not appropriate and cannot be recommended;

- hazardous liquid wastes and hazardous materials containing free liquids[2];
- highly volatile and flammable liquid wastes;
- wastes containing appreciable quantities of mineral oils;
- spontaneously flammable or pyrophoric solids;
- clinical wastes (such as infectious wastes; sharps; etc);
- strong oxidizing/reducing wastes;
- shock sensitive explosives;
- compressed gases;
- highly reactive wastes;
- water soluble non-convertible materials;
- persistent organo-halogen compounds;
- volatile materials of significant toxicity;
- substances that react with water, air or dilute acids and alkalies to produce hazardous gases or hazardous reactions;
- concentrated acids, alkalis;
- empty containers unless they are crushed, shredded or similarly reduced in volume.

31. Liquids placed in a landfill can contribute significantly to leachate generation. To minimize this generation, it is recommended that liquids and materials containing free liquids be excluded from landfills. This prohibition should be extended to include liquids absorbed in materials. At the pressures that could exist in the depths of a landfill, liquids could be "squeezed

[1] Free liquid means uncombined or interstitial liquids.

[2] Views on allowing non-hazardous liquid wastes into a landfill are varied. It is however essential to contain any free liquids in the landfill and to control the water content of the landfill.

out" of the absorbent material to become uncombined and unabsorbed liquids (free liquid) once again. Dilution or blending of a hazardous waste with a non-hazardous material should not be permitted for the sole purpose of diluting it to meet any specified concentration limit.

32. Empty containers such as drums and canisters should not be placed in landfills unless crushed, shredded, or processed by some other means to reduce their volume. This will eliminate the chance of subsidence occurring in the completed landfill due to collapse of the containers under the pressures experienced after burial. If subsidence were to occur, it could threaten the integrity of the landfill cover which would then require on-going maintenance to ensure the security of the landfill.

33. Consideration should be given to the establishment of trace levels of organic hazardous wastes, level of contaminants, particularly halogenated organic compounds which can be landfilled.

34. In principle, hazardous wastes to be deposited in a landfill should receive treatment and/or processing consistent with the best demonstrated available technique appropriate to the type of waste. The objective in applying such a technique should be to minimize the potential release of contaminants to the environment if the security of the landfill system is breached. The appropriate management methods and treatment/processing technology that could be applied to hazardous wastes prior to landfilling could include:

- reduction in waste volumes produced at the source by installing modifications to the industrial process producing the waste or reduction in volume on the landfill site;
- recycling, recovery and/or re-use of various components of the waste;
- physical/chemical treatment for liquids solid separation and detoxification;
- biological treatment for removal of biodegradable/bioconvertible organic components;
- solidification/stabilization/fixation for converting liquid wastes to solid form and for encapsulating hazardous components;
- thermal treatment for destruction of organic wastes.

35. A number of technical measures which are interdependent should be taken to mitigate the impacts of landfill operations on the environment and human health, they concern:

a. **Site selection**. Landfills should be sited, where possible to avoid the possibility of ground water pollution. Where this is not possible, landfills should be designed and constructed to prevent the migration of leachate from the fill to ground water.

b. **Design of operations**. Landfills can be designed and operated in ways that minimize the generation of leachate, by for example tipping vertically rather than horizontally, and by the prompt application of appropriate intermediate cover over the deposited waste, graded to encourage run-off rather than infiltration. Effective compaction of the deposited waste is also important.

c. **Design of landfill** and its proper engineering

d. **Control on incoming waste**. The amounts of waste that directly increase leachate volumes (e.g. wet wastes) should be reduced to a practical minimum.

e. **Landfill closure**. The final closure cover for the landfill can be designed and laid in such a way that infiltration of rainfall into the fill will be greatly reduced.

f. **Careful construction** and operation are essential.

g. Monitoring. A comprehensive programme of monitoring will be required for all landfill sites. It should cover inputs to, contents of and emissions from the site and the surrounding environment. It should be designed to provide advanced warning of any unexpected problems and guidance on remediation possibilities. It should also indicate the point at which the landfill has become stable.

2. *Site selection*

36. In selecting a site for the construction of, for instance, a hazardous waste landfill, several geographical and hydrogeological factors of the location must be considered as well as several potential sites. These factors will have a significant bearing on the level of environmental protection provided by the landfill. Consideration on the future use of the landfill area should be made. Geographical and hydrogeological factors of a site will also influence the design of the landfill including the type of liner system drainage work, and ground water monitors installed.

37. In addition, the degree of urbanization and its proximity to a landfill site should be considered. When an urban centre is near, extra effort must be taken to reduce any social disturbances the landfill may impose. Such disturbances include impacts on the landscape and sewage systems (contaminated by leachate, noise levels, odour levels, vermin, scavengers), and traffic patterns. Also, great care must be taken in developing an emergency preparedness plan in the event of a gas leak or other accident.

38. The site selection process for establishing a hazardous waste landfill must address geotechnical, land-use, biological, socio-economic (it is a widely-held assumption that public opposition to waste management facilities has become one of the critical problems faced in site selection), human and environmental factors. In addition, the process must be carried out in accordance with the environmental assessment requirements specified by regulation or legislation or any relevant jurisdictions. Programme planning, for hazardous landfill sites should be conducted in such a way as to involve local communities and get their input into the process.

39. With the general land area needs and locations identified, approximate costs can be estimated. These costs should include the costs of design, operation, closure, aftercare, financial guarantees for potential damages to third parties, and remediation. Such costs and pertinent factors such as ownership and social acceptability can be used to make an informed decision whether a site represents an economically viable hazardous waste disposal option. If a positive conclusion is reached, detailed technical, biological, social, economical and political analysis of the feasible site could be undertaken.

40. No site should be used for the landfill disposal of hazardous wastes unless the geological and hydrogeological properties of the site have been carefully investigated and found to offer maximal safety for public health and the environment. For instance, a hazardous waste landfill should not be located in a floodplain or be in contact with groundwater. The seasonal height and flow of the groundwater should be established so that the potential for water contamination can be assessed and the location of monitoring wells be established. The site should not be in an area of seismic activity or an area that includes cavities, faults or sinkholes. The integrity of the landfill may be compromised in such areas. The soils at the bottom of the hazardous waste landfill site should be clays and should be several feet thick and relatively impermeable. Thickness of a clay liner of the above dimension delays the problem of losing the protective capacity of the landfill but will not be sufficient to ensure full and complete protection. If such clay soils are not available, appropriate clays or materials may have to be brought to the site to serve as liner material and/or a synthetic flexible membrane liner will have to be installed. Suitable soils should be available as landfill cover material otherwise appropriate soils will have to be brought to the site. There is a concern over the long-term integrity, reliability and operability of liner systems, leachate control systems, and other engineered components of a landfill facility. Both clay and synthetic liners can be damaged during placement of the wastes. In addition, the properties of clay and synthetic liners can be altered by contact with certain wastes such as solvents. Thus, it is essential that landfill design and waste materials be compatible. The site should not be located where normal runoff will inundate the site. Drainage from the surrounding land should be diverted around the site.

41. Annexes I A and I B to these guidelines provide a description of the factors required to select a site and the criteria for landfill site selection. Annex I B is extracted from the World Bank Technical Paper No.93 (see Reference No. 1).

3. *Design considerations*

42. Conceptually, there are two basic approaches to the safe landfilling of problem waste: natural attenuation and containment. In the first approach, landfills designed to receive hazardous wastes are located only in areas where containment attenuation in the environment can be achieved naturally. This approach allows for the possibility of achieving a condition where maintenance is not required over the long term. The major disadvantage in the natural attenuation approach is that it is based largely upon the accuracy of predictions of the level of protection provided by the natural environment. Natural attenuation also requires the presence of suitable hydrological and geological conditions.

43. In the second approach, reliance is placed on engineered facilities rather than on natural attenuation to protect the environment. Typically, landfills designed using this approach combine engineered liners, covers, leachate and/or gas collection and treatment systems to control the release of contaminants into the environment. While engineered containment reduces the potential risk associated with contaminant migration into the environment, questions remain concerning the integrity and functionality of such systems over the long term. The additional cost and responsibility associated with the maintenance and operation of such systems have to be accounted for.

Specially Engineered landfill

44. For specially engineered landfill, receiving wastes, in particular hazardous wastes, a complete site assessment, including development of a contaminant transport model, should be conducted to estimate the potential environmental impact of contaminant migrating from the site at specific locations of concern such as site boundaries and monitoring installation. The landfill site would then be designed in such a manner as to mitigate any impacts identified in the environmental impact assessment.

45. Safe landfill management requires the design of a number of systems, the main purposes of which are to control and minimize leachate, runoff and landfill gas evaporation. The main features of a specially engineered landfill include:

a. Liner systems

46. After a landfill site has been selected, a system to line the landfill must be chosen. The liner system is key to achieving the goal of landfill management to insulate and prevent toxic and other hazardous compounds from being released beyond the confines of the landfill into the environment. Increasingly, double and sometimes even triple liner systems are being selected with liquid collection systems above, below and between liners. Choosing the liner materials compatible with the wastes to be put in the landfill is important. The estimated service life of a liner in a particular exposure condition is also an important factor in selecting a liner material. A variety of complete systems for landfill liners and leachate removal have been designed to protect the environment surrounding the landfill site. The topic of landfill liner systems and leachate control concepts has been the subject of considerable debate and as yet, no consensus has emerged on what the preferred approach should be in general and/or in specific circumstances. One example is represented by a combined liner system (see Figures 2 and 3 with explanatory text).

Engineered containment systems

The bottom and sides of the landfill should be lined with a low permeability containment system. Care must be taken not to penetrate the system during laying or use.

Figure 2 LINER SYSTEM

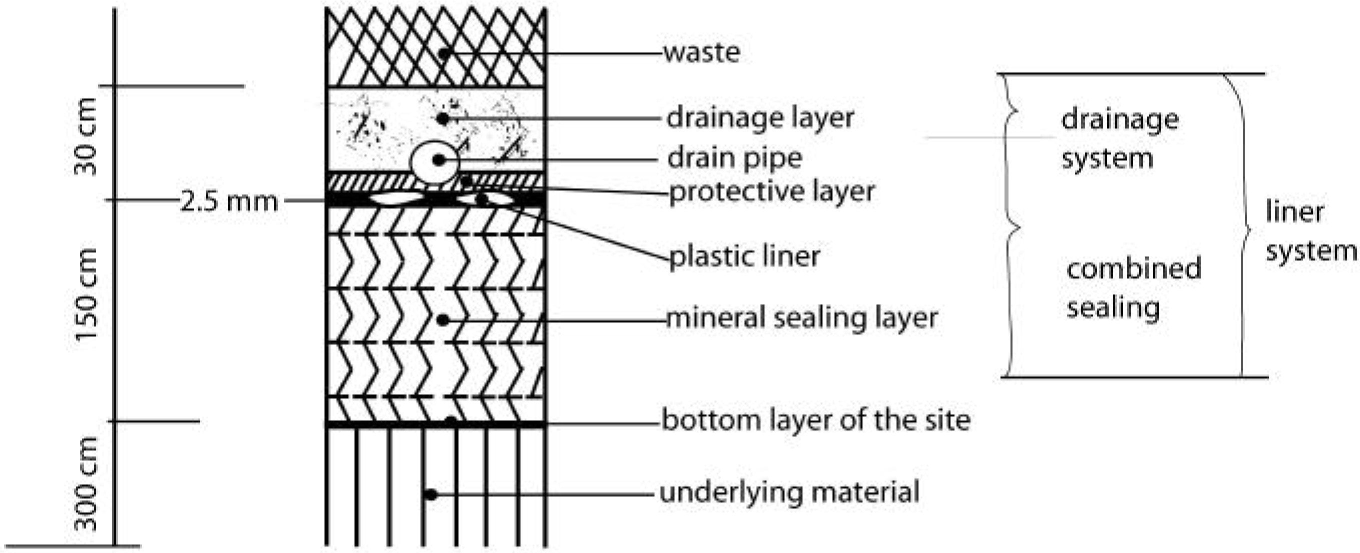


Figure 2 shows one possible system. It consists of the following components which will lie directly above each other:

- A mineral sealing layer (for example, compacted clay) typically 2m thick with a permeability of about 10 m/sec.

- A plastic liner typically 2.5mm thick. Care will need to be taken to avoid leaks and distortions during laying the plastic liner.

- A drainage layer of about 0.3m thickness will be needed. It should be constructed of coarse material, so that over time its permeability will be reduced by clogging.

Drain pipes, collection points and catch pits will be needed to collect and transport leachate.

Figure 3 LANDFILL CAP

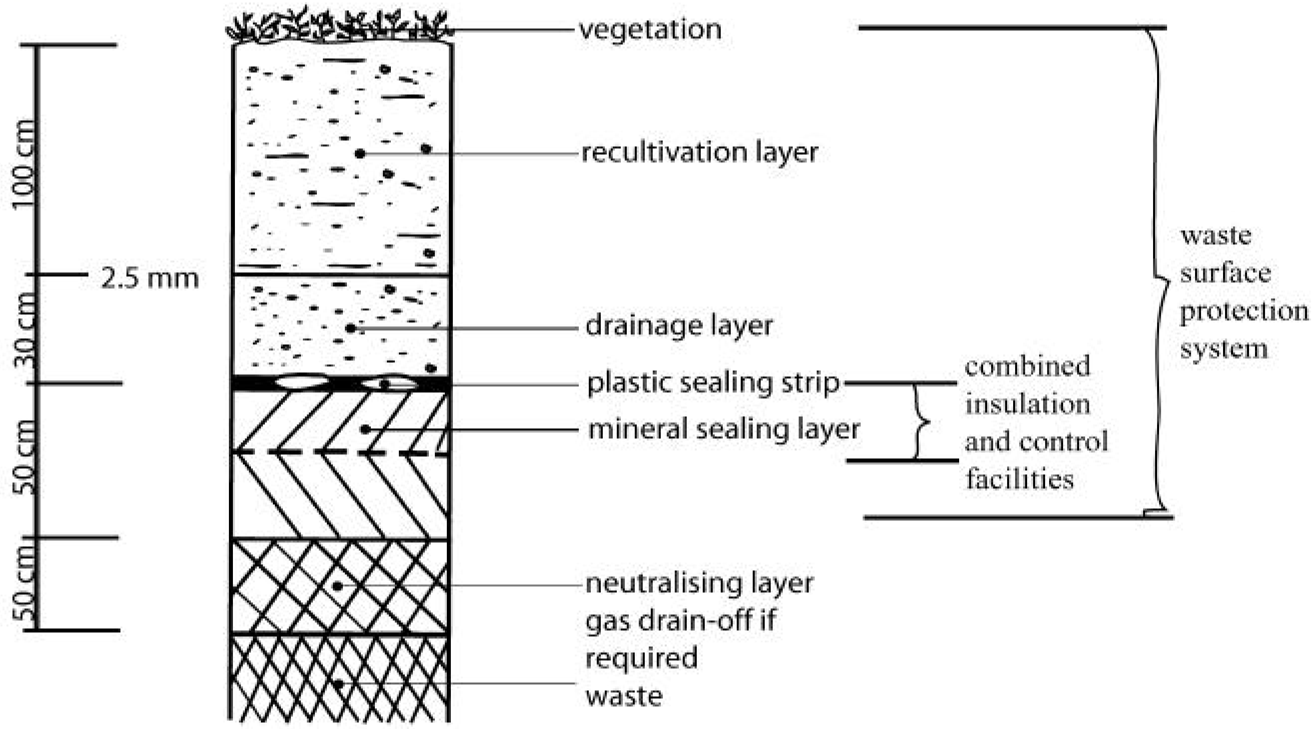


Figure 3 shows one possible construction of a capping system. When each cell is filled, it is covered with a gas collection and neutralisation layer, a combined mineral and plastic sealing layer, surface drainage and soil for cultivation.

b. Leachate control

47. As far as possible, leachate should be avoided. In general, the composition of leachate will be a function of the types and age of wastes deposited, the prevailing physico-chemical conditions, the microbiology and the water balance of the landfill. The main components in the leachate from landfill sites may be grouped into four classes, as follows:

- major elements and ions such as calcium, magnesium, iron, manganese sodium, ammonia, carbonate, sulphate and chloride;
- trace metals such as mercury, chromium, nickel, lead and cadmium;
- a wide variety of organic compounds which are usually measured as Total Organic Carbon (TOC) or Chemical Oxygen Demand (COD); individual organic species such as phenol and chlorinated organic compounds, can also be of concern;
- micro-organisms.

All household waste and most industrial waste will give rise to leachate. Leachate monitoring plays a central role in the management of landfills. The long life of a properly operated landfill, during which time significant changes could take place in landfill practices and in the character of the wastes deposited necessitates monitoring to ensure that the measures taken for environmental protection remain effective. Leachate accumulated within a landfill or collected from drainage systems designed to protect surface waters may need to be disposed of the environment, and treatment may first be needed to reduce its polluting potential (on-site and off-site treatment may be necessary). Leachate is collected in a drainage system, and then exits the landfill. Depending on the nature of the waste and the way the landfill is constructed, the water picks up various contaminants as it passes through the different layers of the landfill. Rainfall, the absorptive capacity of the wastes and the closure cover and capping at the site are critical with regard to the production and control of leachate. A drainage and collection system for leachate must be installed within the landfill that will allow leachate to be pumped to the surface for treatment prior to discharge to water systems. Leachate collected from a problem waste landfill should be examined if it exhibits hazardous characteristics and be treated accordingly.

c. Landfill gas

48. In the first instance, landfill gas should be avoided as far as practicable as they represent a potential risk to people. In this respect, monitoring of landfill gas is most important in particular for chlorinated hydrocarbons, mercury and arsenic. If the specially engineered landfill contains biodegradable/bioconvertible material, measures are needed to allow for the collection, venting, flaring or use of landfill gases that will be produced. These gas control measures must not impair the integrity of the isolation system. Although landfill gas recovery is seen as one of the end-of-the-pipe solution to the problem of escaping landfill gas such as methane, trends in a number of

countries is to discourage or prohibit the landfilling of organic wastes so that any future methane generation in the sites would be minimal or negligible. It should be noted, however, that landfill gas generation will continue because large volume of gas will continue to be formed in existing landfills. Landfill gas may contain up to about 60% methane with the balance being about 40% carbon dioxide with other materials present in trace quantities. The rate of landfill gas generation is very dependent on all the circumstances, but modern landfill practice requires that steps are taken to manage this emission to prevent hazards and when viable recover the gas for use as an energy source. Depending on the nature of the gas released, some form of gas treatment may be desirable. Incineration ***should*** be employed if the gas is rich in methane and/or volatile hydrocarbons. Other gas treatments involve wet scrubbing if the gas has a significant hydrogen sulphide content or carbon absorption in relatively small amounts of volatile hydrocarbons are present in the gas. Gas samples should be obtained and where possible the source "fingerprinted" by identification of constituents. By measuring gas quality in cracks in the soil for monitoring known or anticipated vegetation damage cause by landfill gas. Gas migration control systems should include the monitoring of peripheral boreholes for landfill gas concentration.

d. Security management

49. Access to the site should be strictly controlled. The general public should not normally have access to a problem waste landfill site as is sometimes the case with municipal landfills. Both incoming and outgoing traffic should pass through a single control point for manifest verification, sampling and any other regulatory and administrative actions. A suitable buffer zone should be provided around the perimeter of the site, no development should occur near the landfill (apart from buildings on the site). The buffer zone could incorporate beams and/or trees planted to serve as a visual screen and noise barrier. It will also serve as a margin of safety for neighbours in the event of an accidental release of contaminants. The width of the buffer zone and the visual/noise attenuation features to be incorporated into it may vary according to adjacent land use. The security of the site should be maintained by a perimeter fence to keep out unauthorized people as well as itinerant wildlife. The fence should be posted with signs to identify the site and warn trespassers to stay away. A telephone number to contact in case of emergency should be posted in an obvious place.

e. Closure of the site and long term care

50. The closure system of a completed landfill usually exhibits the following elements:

- Vegetative cover (protection of the covering soil from erosion, maximization of the evapotranspiration rate and landscape quality maintenance;
- A top substrate (with surface drainage to protect the sealing system from damage, frost, etc.);
- A sealing system to prevent infiltration;
- Gas and leachate drainage;

- A levelling layer (compensating for the irregularities of the waste surface).

f. Site monitoring

51. Site monitoring will consist of, inter alia, placing monitoring boreholes to permit the selection of landfill gas migration from the waste; wells may be established for monitoring leachate quality and levels; portable explosion-proof methane detectors should be used.

52. Monitoring is particularly important because it is through long-term monitoring, which may continue for many years, that data is gathered to verify the hydrogeologic assessment and permit the final closure of the site. In order to serve as the reference point for subsequent monitoring efforts, the proposers of new sites should conduct a thorough baseline profile for the proposed site and immediate surrounding areas prior to the establishment of the site. The guarantee of long-term care, until the site can be finally decommissioned, is a particularly difficult and complex problem, depending on site conditions this post-closure period could well exceed 100 years. Specific closure procedures should ensure that the long-term integrity and security of the site is maintained. The closure programme should be directed towards minimizing the need for maintenance of the site after closure. The potential costs for long-term maintenance can be considerable and is an important factor to take into account when selecting a landfill concept. Prior to commencing operation, some form of contingency financing, which would also cover costs of remediation, should be provided in the event that the integrity of the landfill is breached and repairs are required either during its active life or following closure. The amount of financing required will depend on the size of the landfill, the types of wastes placed therein and pertinent site-specific factors.

4. *Operations*

53. The successful implementation of a landfill for the disposal of hazardous wastes hinges on strict control over operating and monitoring procedures. Basic elements of a quality control plan include:

- A good definition of responsibilities for the people involved in the planning, authorization, construction and management of the landfill;
- Appropriate site working plan;
- The qualifications of the workers operating the landfill;
- Work inspection modalities;
- Working inspection modalities for construction materials;
- Documentation demonstrating that the construction works have been carried out under a quality control regime;
- The preservation of all the information on the quality control of the construction works;
- The documentation of management activities and types of wastes stored.

A number of essential administrative procedures should be followed such as: procedures for all operations at the landfill site should be included in a comprehensive manual prepared specifically for the facility; a waste materials inventory control and record keeping system should be developed and rigorously followed at the site; a comprehensive vehicle and equipment maintenance manual should be prepared and kept for all mobile and stationery equipment on the site. The placement of hazardous wastes in the landfill should follow the requirements set forth in the landfill development plan. This would give due consideration to the preferred landfill concept, cell design including a leachate control system, cell development, capping and closure requirements. Placement of wastes must also give due consideration to the segregation of incompatible materials in order to minimize the risk of dangers such as explosions, fires, and the evolution of toxic gases. An emergency procedures plan for dealing with all realistically foreseeable mishaps at the landfill site which could endanger human health or the environment should be prepared and updated on a regular basis. Examples of such incidents include fires, explosions, accidental spills of contaminants in non active areas, and the generation of unanticipated contaminated run-off and/or leachate. Instruction on the emergency procedures plan should be an integral part of the training programme for all employees at the landfill. The inventory of equipment necessary for immediate response to the mishaps outlined in the emergency procedures plan should be kept readily available at the landfill site. Equipment for medium and long-term response actions need not be immediately available on site. However, the emergency procedures plan should note specific locations nearby where it can be obtained on short notice. In this regard, the plan should be prepared in consultation with community emergency response authorities in the vicinity of the landfill site. Copies of the plan should be distributed to all nearby agencies such as police and fire departments, provincial and municipal emergency response teams which might be called upon, and local hospitals.

5. *Landfill costs and costs for containment landfill*

a. Landfill costs (both high and low costs)

54. A study done in the United Kingdom on Urban and Rural municipal waste disposal situation indicated that

Cost of land ranged between	7 to 51 % of total cost per ton
Fixed plant ranged between	3 to 10 % of total cost per ton
Site operations ranged between	18 to 47 % of total cost per ton

Costs	
Post closure costs ranged between	5 to 42 %
Based on margins	4 to 20 %

The total costs ranging between ,7.50 and ,22.50 per ton, these being seen as set to rise between ,9.50 - ,38.50. (1 UK, = US$ 1.50 approximately)
In the case of the landfilling of hazardous wastes into a proper engineered landfill site, the various costs involved could be much higher.

The cost elements in more detail are:

- Cost of land which includes the capital cost of land purchased, leasing costs and land use royalties;

- Fixed plant costs including site buildings, fencing, access roads and stationary equipment and machinery such as weighbridges;

- Site operational costs which includes costs relating to the ongoing activity of landfill operations; e.g. labour, engineering, administration costs, etc.;

- Post closure costs which includes the actual closure costs in addition to ongoing landfill gas monitoring and leachate control, reinstatement, general site maintenance and aftercare as well as provisions for the future liabilities or insurance premiums in relation to this;

- Transport cost which includes all haulage related costs; both of a capital and revenue nature, as well as costs associated with transfer stations where applicable;

- Margin which is the element of profits from the total price per ton of landfilled waste;

- Costs of environmental impact assessment can be considerable for specially engineered landfills.

55. The following elements are relevant:

- If existing landfill facilities are short-lived, demand for new sites in a region will be higher as will be the operating costs for the remaining input if tighter operating costs are applied and if more post operational maintenance is required as a consequence of planning and/or licensing or authorizational conditions.

- The ease of development of voids impacts on all identified cost elements except transport. Additional planning requirements or higher closure standards will increase the costs of developing and operating the landfill. It encompasses all aspects of administration for the preparation of landfill sites i.e., obtaining planning permission and licensing requirements.

- The ease of engineering which is partly linked to the ease of development in that tighter operating requirements will necessitate more extensive or complicated engineering works to ensure compliance with the conditions of site licenses/authorizations

- The proximity of the disposal site to the point of waste arising which affects the transport cost element, and

- Economics of scale which measures the impact of changes in the overall volume of waste to be disposed of on all cost elements except transport rather than how costs per ton vary as a function of landfill site size.

b. Costs for containment landfill

56. Design requirements of a containment system is the most costly form of landfill construction, the principal components being as follows:

- Liner;
- Leachate Collection System (LCS);
- Recirculation system (where appropriate);
- Landfill Gas Collection System;
- Cap;
- Environmental Monitoring System;
- Long term maintenance of all comfort systems.

	Base Area ,/m2
Liner purchase; transport place and compact clay	2 - 50
2,5 mm, HDPE, provide and place	6 - 00
Leachate collection system, Herringbone HDPE pipe and drainage, protection blanket	2 - 50
Gas Collection wells (say 10 m deep site)	1 - 00
Cap purchase; transport; place and compact clay	2 - 50
	,14 - 50/m2

57. A recent costing exercise was carried out in the United Kingdom on five rural dilute and disperse sites of shallow depth 5 - 10 m and average waste inputs of between 80,000 and 200,000 tons per annum. Estimates were made of costs to build new cells in each site to a full containment principle and to a specification incorporating a composite liner.

58. In addition, operating costs were increased to take account of a full Environment Protection Act (EPA 1990) Specification, e.g. supervision by a fit and proper person, Quality Assured (QA) site management, full gate control, leachate and gas removal and treatment, roads and security, pest control and comprehensive environmental monitoring. As the sites were of varying depth and had different waste input characteristics if it was found that the increase in total capital and operating costs amounted to ,4/t and ,7/t. As it now tends to be only the larger sites which can afford the necessary development and infrastructure investment it can be seen that for depths of between 20 - 40 m, these increased costs would be in the much lower range of ,1 - 2,/t for containment, a very small price to pay on the overall costs of waste disposal.

Lateral Containment

59. Gravel extraction operations suggested minimum distance to housing of 150 m, creating void space for waste disposal. Landfill operations suggested minimum distance to housing of 250 m. Hence in general there would be at least 100 m. of excavations around the property (and up to 250 m in some locations) which would not accept waste for disposal.

V. ELEMENTS TO BE CONSIDERED FOR ENVIRONMENTALLY SOUND MANAGEMENT

60. Within a comprehensive waste management system, it should be possible to reduce to a minimum the problem potential by pre-treatment of the waste finally disposed of in a specially engineered landfill. In relation to using specially engineered landfill, it is important to consider affordable techniques that correspond to the needs and capacity of developing countries which are environmentally sound; assessment of the environmental soundness of affordable technologies should be a pre-requisite.

61. Once site selection, design of the landfill and the operative measures have been agreed upon, the fundamental question of deciding which wastes are acceptable for disposal in the hazardous waste landfill remains to be answered. Although site selection and design have taken due consideration of the types of wastes that would be disposed of at the site, rationale for determining acceptability needs to be carefully thought of.

62. Some useful data which may be helpful in establishing appropriate loading (input) rates can be found in the European Commission (EC) amended proposal for a Directive on the Landfill of Wastes COM (93) 275. In this there are figures based on the use of a leachate test to assess whether wastes are hazardous or non hazardous, the latter being disposable into a wider range of disposal sites. The analytical procedures proposed are based on IS0 or DIN tests; other methods are however considered more appropriate in many circumstances and this is recognized. Where hazardous (problem) wastes are to be jointly disposed of in a beneficially interactive mode with municipal waste, a different approach is allowed for, which is based on allowable inputs per ton of municipal waste subject to a number of qualifications. In addition, limit values given in respect of heavy metals and in some cases organic compounds in soil and sewage sludge in the EC Directive on the Use of Sewage Sludge in Agriculture (Directive 86/278/EEC) may also be found helpful.

63. On the basis of past experience the following substances should as far as possible be prevented from entering the water system:

- Organohalogen compounds and substances which may form such compounds in the aquatic environment;
- Organophosphorus compounds;
- Organotin compounds;

- Substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment;

- Mercury and its compounds;

- Cadmium and its compounds;

- Mineral oils and hydrocarbons;

- Cyanides.

64. It would be important to limit the deposit of a number of substances which represent a threat to human health and the environment and can cause serious pollution of all environmental media, such as:

- Metalloids metals and their compounds: Zinc, Copper, Tin, Barium, Nickel, Beryllium, Chrome, Boron, Lead, Uranium, Selenium, Vanadium, Arsenic, Cobalt, Antimony, Thallium, Molybdenum, Tellerium, Titanium, Silver, Biocides and their derivatives;

- Biocides and their derivatives;

- Substances which have a deleterious effect on the taste and or odour of groundwater, and compounds liable to cause the formation of such substances in such water and to render it unfit for human consumption;

- Inorganic compounds of phosphorus and elemental phosphorus;

- Fluorides;

- Ammonia and nitrates/nitrites

It should be noted that ammonia represents a particularly serious and growing threat in terms of water quality and pollution.

V. TECHNICAL COOPERATION

65. Even the countries with years of experience in the disposal of hazardous wastes in specially engineered landfill are faced with great difficulties in ensuring sound and efficient disposal of such wastes.

Co-operation among countries is seen as an essential element to aim at the environmentally sound management of landfills. Training and exchange/sharing of experience, and in particular providing technical and financial assistance to developing countries are considered as an important part of the immediate and more long term measures to take.

66. Chapter 20 of UNCED Agenda 21 recommends that States through bilateral and multilateral co-operation, including the United Nations and other relevant international organizations should:

a. Identify, develop and harmonize methodologies and environmental quality and health guidelines for safe waste discharge and disposal.

b. Review and keep abreast of developments and disseminate information on the effectiveness of techniques and approaches to safe waste disposal and ways of supporting their application in countries.

VI. CONCLUSION

67. It can be seen from the foregoing material that the setting up, operating and closing of any landfill requires a highly professional approach. This is even more the case for specially engineered landfills where up to 36 scientific and technological disciplines may need to be accessed in pursuit of an optimal environmentally sound overall operation.

68. The essential core disciplines are seen as geology, hydrogeology, civil and mechanical engineering, chemistry and biochemistry and because active deposits are by way of being macro reactors, chemical and biochemical engineering are also involved. It is this macro aspect which makes the application of an efficient unit operational process to landfill difficult and as a consequence of this is promoting an increasing degree of pre- and post-deposit treatment to render materials to be deposited, environmentally inert or to optimize the in situ stabilization process.

GLOSSARY

Aerobic Decomposition	Occurs in moist conditions in the presence of i.e. oxygen (produces strong leachate and no gas)
Anaerobic Decomposition	Occurs in moist conditions in the absence of i.e. oxygen (produces landfill gas and weak leachate)
Attenuation	Gradual reduction in concentrations of contaminants in leachate, due to physical, chemical and biological activities as it passes through soil and various subsoils
Biodegradable	Organic material which can be broken down chemically by biological action
Cap	A layer of clay or other material to prevent ingress of rainwater
Clay layer	A layer of clay applied to the base of walls of a site to prevent leachate or gas migration. Also applied to surface - see Cap
Cover material	Any inert material used to cover waste during landfill; usually applied towards the end of the working day
Containment site	One where the bottom and sides are or have been made impermeable to liquids using natural elements or synthetic liner
Groundwater	Water occurring naturally, below the surface
Hazardous wastes	Those wastes which are listed in Annex I to the Basel Convention and exhibit one or more of the hazardous characteristics specified in Annex III to the Convention.
Heavy metals	Usually refers to lead, zinc, cadmium, copper
Hydrogeology	The study of groundwater movement and chemistry, etc.
Lagooning	A technique for settling out fine solids by forming a settling pond with a long residence time, usually days or weeks
Landfill gas	Generated under anaerobic conditions and is a mixture of methane (CH4) and carbon dioxide (CO2) approximately 60:40 by volume
Leachate	Liquid drainage from a landfill site containing dissolved solids and products of decomposition of organic matter

Leachate recycling	Pumping of leachate from a collecting sump back over the surface of the waste and letting it run into the waste in order to accelerate decomposition both of the waste and organic compounds in the leachate
Municipal waste	Wastes collected by municipalities or by their order, including wastes from households (not household hazardous wastes) and similar wastes from commercial activities, office buildings, institutions and industry that dispose of waste at municipal facilities.
Stabilization	Achieved when all organics have decomposed

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ANNEXES

ANNEX I

A. SITING CHARACTERISTICS

B. LANDFILL SITE SELECTION CRITERIA

ANNEX II

ELEMENTS FOR CONTROL AND MONITORING PROCEDURES

ANNEX I A

SITING CHARACTERISTICS[3]

In selecting a site for the construction of a hazardous waste landfill, several geographical and hydrogeological factors of the location must be considered. These factors will have a significant bearing on the level of environmental protection provided by the landfill. Geographical and hydrogeological factors of a site also will influence the design of the landfill, including the type of liner system, drainage network, and groundwater monitors installed.

In addition, the degree of urbanization and its proximity to a landfill site should be considered. When an urban centre is near, extra effort must be taken to reduce any social disturbances the landfill may impose. Such disturbances include impacts on the landscape and sewage systems, noise levels, odour levels, and traffic patterns. Also, great care must be taken in developing an emergency preparedness plan in the event of a gas leak or other accident.

Hydrogeological Characteristics

All drinkable water supply points, and distances between these points, in the area surrounding a landfill should be identified. The landfill must be located far enough away from these sources so that in the event of an accident and contamination, there will be enough time to provide warning and alternative drinking water supplies to communities that rely on the water aquifer that could be contaminated.

The surface hydrology of an area also should be considered, so as to avoid areas prone to flooding or susceptible to erosion. At a minimum, 100 years of return time of frequency, is recommended for flooding.

In studying the hydrology of an area, seasonal variations in water table depth, and the table's maximum historical height, must be determined. The depth of a landfill bottom must be placed some meters above the maximum water table increase.

Geographical Characteristics

The most important geographical factor involved in choosing a landfill site is the stability of the area. The morphology of a location also must be carefully considered.

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[3] Selection of siting characteristics prepared by ISWA Series 1991, Number 1 - Safe Hazardous Waste Management Systems A - State-of-the-Art Guide for Decision Makers ISWA Working Group on Hazardous Wastes.

Depending on geographical and morphological factors, three different types of landfills are generally constructed: superficial, depression and slope. In addition, underground structures located in lithologically stable areas are sometimes used for the disposal of highly toxic stable wastes.

ANNEX I B

LANDFILL SITE SELECTION CRITERIA

Engineering

Geophysical site (geographical criteria): Should be large enough to accommodate waste for life of production facility.

Proximity: Locate as close as possible to production or treatment facility to minimize handling and reduce transport cost. Locate away from water supply (suggested minimum 500 feet) and property line (suggested minimum 200 feet, more for landfill gas).

Access: Should be all-weather, have adequate width and loan capacity, with minimum traffic congestion; one way system on site whenever possible.

Topography: Should minimize earth-moving, take advantage of natural conditions. Avoid natural depression and valleys where water contamination is likely.

Geology: Avoid areas with earthquakes, slides, faults, underlying mines, sinkholes, and solution cavities.

Soils: Should have natural clay liner or clay available for liner, and final cover material available.

Environmental

Surface water: Locate outside 100-year floodplain. No direct contact with navigable water. Avoid wetlands.

Groundwater: No contact with groundwater. Base of fill must be above high groundwater table. Avoid sole-source aquifer. Avoid areas of groundwater recharge.

Air: Locate to minimize fugitive emissions and odour impacts.

Terrestrial and aquatic ecology: Avoid unique habitat area (important to propagation of rare and endangered species) and wetlands.

Noise: Minimize truck traffic and equipment operation noise.

Land use: Avoid populated areas and areas of conflicting land use such as parks and scenic areas.

Cultural resources: Avoid areas of unique archaeological, historical and paleontological interest.
Legal/regulatory: Consider national, regional and local requirements for permits.
Public/political: Gain local acceptance from elected officials and local interest groups.

Economic

Property acquisition: Actual land cost plus related costs.

Site development: Excavation, grading, liner, new roads, and other development costs.

Annual costs: Fuel costs, operating labour, maintenance, land preparation, utilities, and overhead.

Salvage value: Do not consider: site probably will not be an asset.

Conflicts with the objective of setting up and operating towards a stable system particularly in respect of organic matter and in some cases heavy metals (comment seen as relevant to mono deposit with ong term storage prospects).

ANNEX II
ELEMENTS FOR CONTROL AND MONITORING PROCEDURES

1 METEOROLOGICAL DATA

1.1 States should supply data on the collection method for meteorological data. The data shown in table 1 could be collected from monitoring at the specially engineered landfill or from the nearest meteorological station.

1.2 It is recognized that water balances are an effective tool for evaluating whether leachate is building up in the landfill body or whether the site is leaking.

		Operation phase	**Aftercare phase**
1.1	Volume of precipitation	Daily	Daily, added to monthly values
1.2	Temperature (min., max., 14.00h CET)	Daily	Monthly average
1.3	Direction and force of prevailing wind	Daily	Not required
1.4	Evaporation (lysimeter)[4]	Daily	Daily, added to monthly values
1.5	Atmospheric humidity (14.00h CET)	Daily	Monthly average

TABLE 1

2 EMISSION DATA: WATER, LEACHATE AND GAS CONTROL

2.1 Sampling of leachate and surface water if present must be collected at representative points. Sampling and measuring (volume and composition) of leachate must be performed separately at each point where leachate is discharged from the site.

2.2 Monitoring of surface water if present shall be carried out at not less than two points, one upstream from the landfill and one downstream.

2.3 Gas monitoring must be representative for each section of the specially engineered landfill.

2.4 Table 2 indicates the frequency of sampling and analysis.

[4] Or through suitable methods

		Operating phase	Aftercare phase [3]
2.1	Leachate volume	monthly [1][3]	every 6 months
2.2	Leachate composition [2]	quarterly [3]	every 6 months
2.3	volume <u>and composition</u> of surface water [7]	quarterly [3]	every 6 months
2.4	Potential gas emissions and atmospheric pressure [4] (CH_4, CO_2, O_2, H_2S, H_2 etc.)	monthly [3][5]	every 6 months(6)

(1) The frequency of sampling could be adapted on the basis of the morphology of the landfill waste (in tumulus, buried, etc.). This has to be specified in the permit.
(2) The parameters to be measured and the substances to be analyzed vary according to the composition of the waste deposited; they must be laid down in the permit document and reflect the leaching characteristics of the wastes.
(3) If the evaluation of data indicates that longer intervals are equally effective, they may be adapted. For leachates, conductivity must always be measured at least once a year.
(4) The measurements are relevant mainly to landfills receiving large quantities (>25% w/w) of organic waste.
(5) CH_4, CO_2, O_2 regularly, other gases as required, according to the composition of the waste deposited, with a view to reflecting its leaching properties.
(6) Efficiency of the gas extraction system must be checked regularly.
(7) On the basis of the characteristics of the landfill site, the competent authority may determine that these measurements are not required.

2.1 and 2.2 apply only where leachate collection takes place.

TABLE 2

2.5 For leachate and water a sample, representative of the average composition, shall be taken for monitoring.

3. PROTECTION OF GROUNDWATER

A. Sampling

3.1 The measurements must be such as to provide information on groundwater likely to be collected by the discharging of waste, with at least one measuring point in the groundwater inflow region and two in the outflow region. This number can be increased on the basis of specific hydrogeological survey and the need for an early identification of accidental leachate in the groundwater.

3.2 Sampling must be carried out in at least three locations before the filling operations in order to establish reference values for future sampling.

B. Monitoring

3.3 The parameters to be analyzed in the samples taken must be derived from the expected composition of the leachate and the groundwater quality in the area. In selecting the parameters for analysis account should be taken of mobility in the groundwater zone. Parameters could include indicator parameters in order to ensure an early recognition of change in water quality.[5] Table 3 provides information on the selection of parameters.

	Operation phase	Aftercare phase
Level of groundwater	Every 6 months (1)	Every 6 months (1)
Groundwater composition	Site-specific frequency (2)(3)	Site-specific frequency (2)(3)
(1) If there are fluctuating groundwater levels, the frequency must be increased. (2) The frequency must be based on possibility for remedial actions between two samplings if a trigger level is reached, i.e. the frequency must be determined on the basis of knowledge and the evaluation of the velocity of groundwater flow. (3) When a trigger level is reached (see C), verification is necessary by repeating the sampling. When the level has been confirmed, a contingency plan (laid down in the permit) must be followed.		

TABLE 3

C. Trigger levels

3.4 Significant adverse environmental effects should be considered to have occurred in the case of groundwater, when an analysis of a groundwater sample shows a significant change in water quality. A trigger level must be determined taking account of the specific hydrogeological formations in the location of the landfill and the groundwater quality. The trigger level must be laid down in the permit whenever possible.

3.5 The observations must be evaluated by means of control charts with established control rules and levels for each downgradient well. The control levels must be determined from local variations in groundwater quality.

5 Recommended parameters: pH, TOC, phenols, heavy metals, fluoride, As, oil/hydrocarbons.

4 TOPOGRAPHY OF THE SITE

4.1 Data on the specially engineered landfill body should be collected as indicated in Table 4

		Operating phase	After-care phase
4.1	Structure and composition of landfill body [(1)]	yearly	
4.2	Settling behavior of the level of the landfill body	yearly	yearly reading
(1) Data for the status plan of the concerned landfill: surface occupied by waste, volume and composition of waste, methods of depositing, time and duration of depositing, calculation of the remaining capacity still available at the landfill.			

TABLE 4

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal was adopted in 1989 and entered into force in 1992. Presently, there are more than 150 Parties to the Basel Convention. Its objective is to protect human health and the environment from the adverse effects caused by the generation, management and transboundary movements of hazardous wastes.

The fundamental aims of the Basel Convention are the reduction of the transboundary movements of hazardous wastes, the prevention and minimization of their generation, the environmentally sound management of such wastes and the active promotion of the transfer and use of cleaner technologies.

In December 1999, the Parties to the Basel Convention adopted the Basel Protocol on Liability and Compensation for Damage resulting from the Transboundary Movements of Hazardous Wastes and Their Disposal.

www.basel.int

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Sales No. E.02.III.D.203
ISBN 92-1-158603-8
ISSN 1020-8364

UNEP