GUIDELINES FROM THE DANISH ENVIRONMENTAL PROTECTION AGENCY

No.

LANDFILLING OF WASTE

1997

MINISTRY OF ENVIRONMENT AND ENERGY
DANISH ENVIRONMENTAL PROTECTION AGENCY

Contents

Preface

These Guidelines should be regarded as a contribution to an overall environmental policy in which the overall objective is to reduce the amounts of and environmental impact from all types of waste, to channel the greatest possible quantity of waste to recycling, and to incinerate waste with energy recovery.

Landfilling will thus become the form of treatment which has the lowest priority.

The starting point for these Guidelines is an objective of the environmental policy to the effect that **each generation must deal with its own waste so that it does not become an environmental threat to future generations.** In other words, the starting point for these Guidelines is basically different from the earlier guidelines for waste landfilling. Chapter 2: ”Overall Landfill Strategy” describes the new principles on which the Guidelines are based.

These Guidelines for landfilling of waste supersede the Danish Environmental Protection Agency’s earlier Guidelines No. 4/1982: ”Guidelines for Landfilling of Waste”.

TheGuidelines are being published in spite of the fact that, as they go to press, work isin progress to draw up a common EU directive on the landfill of waste. The Guidelines are closely associated with the principles of the draft directive submitted by the Commission on 5 March 1997, but it is reasonable to assume that amendments/additions will be made to these Guidelines as soon as the draft directive has been finally adopted.

1 Introduction

1.1 General Notes

Environment-policy objective
These Guidelines supersede the Danish Environmental Protection Agency's earlier Guidelines No. 4/1982: "Guidelines for Landfilling of Waste". These Guidelines are based on a principle which is fundamentally different from earlier guidelines for landfilling of waste. Thus, the starting point for these Guidelines is that the properties of waste to be landfilled must be known - including the leaching behaviour of the waste. This means that knowledge of the waste to be landfilled becomes the most important factor in environmental protection. At the same time the Guidelines are based on the objective that each generation must deal with its own waste; this implies that the waste landfilled must be of such a nature that it is likely that leachate from the waste can be accepted in the surrounding groundwater within not more than 30 years. This environmental policy objective should be seen in the light of the fact that environmental protection systems at landfills cannot be expected to work eternally. The new overall landfill strategy is described in Chapter 2.

The term "landfill" is explained in Chapter 3.

Acceptance categories
Acceptance criteria for waste going to landfill are one of the fundamental factors in the new Guidelines. In the future only certain types of waste can be accepted for landfilling. This waste is classed in different categories according to the properties of the waste.

The starting point for the acceptance criteria is detailed knowledge of the chemical composition and expected leaching behaviour of the waste. At the time of publication of these Guidelines this basis is available for only a few types of waste. Substantial development work is in progress at national as well as EU level to establish the final criteria for waste going to landfill. Until the development of criteria and test methods to verify these are complete, waste acceptance procedures at landfills must rely on positive lists for some time yet. The principles for establishing these positive lists are described in Chapter 4. When the final criteria and test methods are available, special guidelines will be drawn up by the Danish Environmental Protection Agency to replace Chapter 4 of these Guidelines.

Other contents of Guidelines
Chapters 5 to 12 of the Guidelines describe Preliminary Investigations (Chapter 5), Layout (Chapter 6), Liner Systems (Chapter 7), Leachate Collection (Chapter 8), Gas Management (Chapter 9), Operation (Chapter 10), Control (Chapter 11), and Restoration (Chapter 12). The degree of specification ranges from functional requirements to detailed guiding directions. The detailed guiding directions should be regarded as a support only and are not binding to the extent that better methods - including alternative ones - can be used to comply with the Guidelines' intentions. The guidelines for bentonite liners and composite liners in Chapter 7 are applicable only until a revised edition of DS/R 466 becomes available, as it includes details of bentonite liners. The revised edition of DS/R 466 will be replaced by common European standards when available.

The Guidelines contain no exhaustive presentation of all matters that can or must be included when applying for and/or considering applications for permit of expansion or establishment of landfills, including:

- Matters relating to cleaner technology;
- assessment of the effects of certain public and private projects on the environment
  (EIA rules);
- the authorities' responsibility;
- regional and local planning;
- rules on occupational health and safety;
- other matters relating to the permitting of listed activities (Part V of the Danish Environmental Protection Act); and
- other guidelines and rules in this field.

Guidelines have been drawn up for most of the above-mentioned items; please refer to these.

1.2 Scope and delimitation of the Guidelines

Scope
The Guidelines apply to the permitting and construction of all new landfills as well as to any significant expansion of existing facilities.

At the time of publication of these Guidelines the sections 4.3: "Acceptance criteria" and 4.4: "Test levels" cannot be implemented in full because of the lack of scientific basis available at this time. These sections therefore should not achieve full validity until it is *either* required by law by virtue of adoption of the EU directive on the landfill of waste *or* when the scientific basis has been provided - so that acceptance criteria and testing can be carried out for all landfills in Denmark, including existing facilities.

However, level-3 testing will always have to be performed.

Delimitation
The Guidelines do not cover landfills for hazardous waste, except that the principles outlined in these Guidelines must be applied, as a minimum, to the permitting and construction of landfills for hazardous waste.

The purpose of the Guidelines is solely to state principles and guidelines, and they are *in no way* intended to replace the detailed technical planning and investigation which must precede all decisions in respect of planning, construction and operation of landfills.

1.3 Delimitation of the Guidelines in relation to other Danish legislation and standards

Coastline proximity
The location of suitable sites for landfills must be based on the principle of coastline proximity, which is described in the Danish Ministry of the Environment's letter of 27 December 1991. Any selection of suitable sites for the location of landfills occurs in connection with the regional planning and on the basis of the legislation applying to this field. Therefore, principles of location are

not dealt with in these Guidelines.

It appears from sect. 50 of the Danish Environmental Protection Act that landfills may be owned only by public authorities. In view of the public ownership of landfills these Guidelines do not include directions for the forming of foundations or provision of security for the restoration, closure and aftercare of landfills.

1.4 Target group for the Guidelines

These Guidelines are addressed to all those who are dealing with the landfill of waste. It is thus envisaged that the Guidelines should be used by authorities in connection with any permitting and inspection of landfills. For those who are considering to establish a landfill the Guidelines are intended to be a directive for their planning, preliminary investigation and preparation of project documentation when applying for environmental permits.

2 Overall Landfill Strategy

Knowledge of the waste going to landfill and the location of the landfill are the most important factors of environmental protection in the landfill of waste.

The starting point for the strategy for waste landfilling is that each generation must deal with its own waste. At the same time, a ”generation” is the realistic time horizon where active, environmental protection systems can be expected to work. Finally, it is the time horizon for the length of time where leachate management, optimum control, and inspection are likely to be carried out after closure of the landfill.

This implies that the landfilled waste must have a composition which renders it probable that leachate from the waste can be accepted in the surrounding groundwater within a time horizon of 30 years. During the period until leachate from the waste is acceptable in the surroundings, a landfill constitutes a potential source of pollution.

Because some of the active, environmental protection systems can fail, steps must be taken to ensure that the location of the landfill is environmentally acceptable.

Location
Any expansion of existing landfills as well as the location of new sites must therefore be made in the light of a number of overall environmental considerations. The result of this is sites which are located, primarily, just behind the coastal zone and in areas with limited drinking water interests. If this location is not possible, a location closer to the coast may be the solution - except that the preservation of open stretches of coast and the regard for the interests in recreation, natural and cultural patrimony must be allowed for. Locations near watercourses and lakes and in the interior of the country should be avoided if at all possible.

Sites with a simple well-defined geology and hydrogeology should be preferred.

Landfills
In order to gather the pollution potential from the landfilled waste in few places, waste must be landfilled in few facilities. It is therefore intended that the number of active landfills should be reduced (as per the Ministry of Environment’s letter of 27 December 1991 concerning the geographical location of landfills in connection with the 1993 revision of regional plans). This makes it possible to carry out a target-oriented and effective monitoring of the impact of the facilities on the environment.

Waste acceptance criteria
Before waste is accepted at a landfill it must be rendered probable that leachate from the waste will be acceptable in the groundwater of the area within not more than 30 years and thereafter. If this is not the case, waste must be pre-treated in such a manner that the criteria can be met before landfilling.

No waste may be mixed or diluted in order to meet this criterion.
Waste will be divided into types which can be expected – directly or after pre-

treatment - to be of the same nature. There must be no mixing of different types of waste which could trigger processes that alter the knowledge of the nature and behaviour of the leachate with time.

Waste that can be treated in other environmentally sound manners by means of existing methods should not be landfilled. Waste suitable for incineration and recyclable materials therefore should not be landfilled. As from 1 January 1997 the Statutory Order on Waste contains a requirement for the local councils to provide regulations that assign waste suitable for incineration to this treatment option. As from the same date there is a requirement for the local councils to provide regulations that ensure source separation and recycling of construction and demolition waste.

Layout and operation
Landfills are subdivided into landfill units. Landfill units are established with environmental protection systems adapted to the types of waste intended to be placed there.

In exceptional cases, a mono-landfill may be set up for large quantities of a single type of waste.

- *Active environmental protection systems*
- Basically, all leachate must be collected, treated and monitored from each individual landfill unit by means of active environmental protection systems. These systems must provide optimum environmental protection throughout the active phase of the landfill unit.

For this purpose ”active environmental protection systems” are components such as liners, drains, pumps, discharge to treatment plants, etc. If these fail, optimum environmental protection is no longer achieved. Optimum environmental protection is necessary until leachate from the waste is acceptable in the groundwater or surface water. Until then, active environmental protection systems must be intact or capable of being replaced on an ongoing basis. Active environmental protection systems require monitoring.

Landfill units that are intended only to receive waste from which leachate will be acceptable in the surrounding groundwater at a given location can be established with reduced - or exclusively with passive - environmental protection systems. These landfill units can be accepted on the basis of detailed advance knowledge of the geological and hydrogeological conditions and wetland conditions around the given location - as well as of the leaching behaviour of the waste and an overall assessment of the impact on the environment.

- *Passive environmental protection systems*
- Passive environmental protection systems are components which protect the environment without maintenance. These components may be embankment systems, low-permeable bottom liners, final covers, surface drains, vegetation, etc. Such systems are likely to remain effective for several hundred years.

Final cover
Each unit in a landfill must receive a final cover as and when the individual cells of the unit reach the defined landscape profile.

The final cover must be adapted to the expected leaching behaviour of the waste. Tight final covers are unacceptable until the leachate has reached a stable condition that can be accepted in the surrounding groundwater.

From active to passive
The active systems of a landfill unit may become passive systems when the leachate from the individual unit becomes acceptable in the percolating water in the area surrounding the landfill. In each particular case this must be determined on the basis of an assessment of the impact on the surrounding environment.

The time when the landfill can go to passive operation is established in the light of concrete assessments of the relevant monitoring activities, and knowledge is obtained of the actual leaching pattern of the waste.

Monitoring and control
The most significant self-control for a landfill must be the control of waste received. Another important factor in connection with self-control is the supervision of the establishment of active environmental protection measures. During the phase when the environment protection systems of a landfill are active, the leachate must be monitored and controlled. When the active systems become passive ones, the monitoring and control of leachate may cease.

Control of the groundwater and wetlands around a landfill must verify that the pollution is no greater than assumed in the permit of the facility. The extent and duration of the control activities in the landfill's passive phase are determined on the basis of a concrete assessment of the results of the controls as recorded during the landfill's active phase and the actual leaching behaviour of the waste. The control activities are the responsibility of the owner of the landfill.

3 Definition of Landfills

Landfills are delimited constructions where waste can be landfilled under controlled and environmentally sound conditions. Before being landfilled the waste must have been inspected and checked.

3.1 **Definition and strategy**

”Landfill” is a collective term for facilities subject to authorisation for the landfill of waste.

Landfills are sites where various types of waste can be gathered and an effective waste control carried out to ensure that the landfilling is environmentally optimal.

A landfill must be established with landfill units corresponding to a division of waste into various types the properties of which are - directly or after pre-treatment - of the same nature. This system allows for differentiated management of the leachate from different types of waste. Furthermore, a higher degree of specific control of the waste at the tip face is achieved - so as to ensure that the waste is placed in the proper landfill unit.

Landfill units are established with different environmental protection measures - in terms of operation and/or design - depending on the nature which the waste is expected to have.

Each landfill unit is subdivided into cells; the size of the cells is determined by constructional and operational conditions.

If large quantities of a single type of waste are to be landfilled, a mono-landfill may be established. The environmental protection systems are adapted to the type of waste.

Every landfill represents a potential pollution risk during the period until leachate from the waste is acceptable in the surroundings. Therefore, if some of the active environmental protection systems fail, measures must be taken to ensure that the groundwater and surface water are not affected.

Landfills should be located, primarily, just behind the coastal zone and in areas with limited drinking water interests, see Chapter 5: ”Preliminary Investigations”.

Active and passive environmental protection systems are defined in Chapter 6: ”Layout”.

3.2 **Landfill units**

A landfill may consist of a number of units where specified types of waste are received - or it may be a mono-landfill for a single type of waste.

Landfills may be laid out with active or passive environmental protection

systems depending on the type of waste it is intended to receive.

3.2.1 **Landfill unit**

A landfill unit is a delimited and well-defined area where types of waste with uniform composition and leaching behaviour are placed together under controlled, environmentally sound conditions.

Subdividing the landfill into landfill units provides access to perform specific control of the types of waste landfilled in each unit.

Each landfill unit is equipped with facilities for separate leachate management and different levels of environmental protection systems - corresponding to the types of waste which the unit is expected to receive.

In practice, a typical landfill could be expected to contain the landfill units indicated in Table 3.1.

Table 3.1.
Landfill units with examples of the nature and categories of waste, and the environmental protection systems.

	LANDFILL UNIT		
	Inert waste	Mineral waste	Mixed wastes
NATURE OF WASTE	Waste which is non-reactive (both physically and chemically) and from which the release of substance is negligible	Waste of a mineral nature (high content of salts and metals) with little or no content of organic matter	Mixture of slowly degradable organic matter and mineral components. Non-combustible nature
ENVIRONMENTAL PROT. SYSTEMS	Passive/active	Active/passive	Active

Active environmental protection systems are pre-evaluated in relation to the type of waste in question. Under normal circumstances, active environmental protection systems will include collection and disposal of leachate.

Passive environmental protection systems can be used as the sole system only where a careful assessment has been made of the geological and hydrogeological conditions in the area around the relevant site - and where the impact on and possible risks to the environment have been assessed in advance, particularly on the basis of knowledge of the waste, and found acceptable.

In cases where it may be necessary to landfill waste with a high organic content, a landfill unit at the facility must be laid out as a ”bioreactor landfill”. The operation of such a unit must be arranged so that the decomposition of the organic waste is optimised with a view to recovery of the generated methane gas for energy purposes. Annex C contains a description of a ”bioreactor landfill”.

3.2.2 **Mono-landfill**

A ”mono-landfill” is a landfill which receives only one specified type of waste under controlled and environmentally sound conditions. The type of waste must be known with regard to origin, composition and likely leaching behaviour.

Mono-landfills are used where there is a need to dispose of exceptionally large quantities of a single type of waste from one or a few sources.

A mono-landfill must be laid out as *one landfill unit* with active and/or passive environmental protection measures adapted to the composition of the particular type of waste and its expected leaching behaviour.

Active environmental protection systems are pre-evaluated in relation to the type of waste in question. Under normal circumstances, active environmental protection systems will include collection and disposal of leachate.

Passive environmental protection systems can be used as the sole system only where a careful assessment has been made of the geological and hydro-geological conditions in the area around the relevant site - and where the impact on the environment has been assessed in advance, particularly on the basis of knowledge of the waste, and found acceptable.

Table 3.2 below provides examples of different mono-landfills.

Table 3.2
Examples of mono-landfills.

MONO-LANDFILL FOR:	**SINGLE INDU-STRY/TRADE**	**RESIDUES FROM INCINERATION**	**RESIDUES FROM POWER PLANTS**
TYPES OF WASTE (EXAMPLES)	Residues from manufacturing industry	Slag	Fly ash
NATURE OF THE WASTE	Uniform, mineral product with a content of few, known components. Quick/slow leaching.	Uniform, mineral product with a moderate content of leachable salts and a moderate to slight content of readily leachable trace elements	Uniform, fine-grain mineral product with a moderate to slight content of leachable salts and a moderate to slight content of readily leachable trace elements
ENVIRONMENTAL PROT. SYSTEMS	Active	Active/passive	Passive

4 Waste Acceptance Procedures

This chapter will be replaced, in the long term, by separate guidelines from the Danish Environmental Protection Agency. This chapter describes only the principles of the future procedures for acceptance of waste at landfills. Until final guidelines are available, the principles of this chapter must be applied. See also sect. 1.2: ”Scope and Delimitation of the Guidelines”.

4.1 Definition and strategy

The most significant environmental protection factor in landfilling of waste must depend on the nature of the waste to be landfilled. Thus, prior to acceptance of waste at landfills, the short- and long-term impact of the waste on the environment must be considered. Waste going to landfill must have a composition that can ensure that all active environmental protection systems in the area where the waste is placed can be made passive as soon as possible. Waste must not constitute a potential pollution risk beyond the period where leachate can realistically be collected and treated, and control and inspection of the closed landfill can be carried out. In respect of waste going to landfill it must thus be reasonably certain that leachate from the waste will be acceptable in the groundwater of the relevant area within 30 years of landfilling.

It is intended to divide waste into types the properties of which can be expected – directly or after treatment - to be of the same nature, and thereby determine at which landfill unit the waste can be placed. This permits an appropriate and separate treatment and monitoring of leachate from different types of waste.

Furthermore, it is intended to assess if the waste is indeed suitable for landfilling in its present form.

No waste may be diluted in order to meet the above criteria. Any mixing of different types of waste for the purpose of changing the composition and behaviour of the individual types of waste with time, cannot be accepted.

Waste that can be treated in other environmentally sound manners by existing methods should not be landfilled. Waste suitable for incineration and recyclable material therefore *should not* normally be landfilled.

4.2 Waste categories

Waste categories that can be accepted are determined on the basis of available units at the relevant landfill, cf. Chapter 3, Table 3.2.

In general, three categories are established - with the following characteristics:

Inert waste

- Category I: Inert waste is
  inorganic waste containing no reactive (neither physically nor chemically) substances. The release of substances and the eco-toxicity must at all times be negligible.

Mineral waste

- Category II: Mineral waste is

inorganic mineral substance with low organic content. Its ability to dissolve in or react chemically with water must be limited.

Mixed wastes

- Category III: Mixed wastes are
  a mixture of organic and inorganic substances which cannot be separated or can be separated only with difficulty and with as excessive consumption of resources. Waste must have a limited content of organic, slowly degradable substances and must not have a high content of readily soluble mineral components.

Potential problem wastes

If waste does not fall directly under one of the above categories, it must be regarded as potential problem wastes. Such waste must be further examined before it can be assigned to one of the categories. Alternatively, the waste must be pre-treated.

List of examples

Table 4.1 contains examples of waste types which are likely to fall under one of the Categories I, II or III. Any final confirmation thereof must be based on the acceptance criteria outlined in sect. 4.3.

Table 4.1

Types of waste that are likely to fall under one of the categories defined above.

	CATEGORY I INERT WASTE	CATEGORY II MINERAL WASTE	CATEGORY III MIXED WASTES
EXAMPLES OF WASTE TYPES	• asbestos • porcelain • glass • porous concrete • tempered glass Wool • Bricks Reinforced concrete	• gypsum waste • slag • fly ash • road sweepings • foundry sand • soil contaminated with metals	• Residues from sorted bulky waste • residues from sorted construction and demolition waste • sand from waste water treatm. pl.

4.3 **Acceptance criteria**

It is the governing principle that waste can be accepted at landfills on the basis of a positive list drawn up in the light of the knowledge of the origin, composition and properties of the waste.

Any positive list must be specific and related to each single landfill unit at the facility. The positive list is to be based on the categories of waste defined in sect. 4.2 out of regard for the protection of:

- the surrounding environment;
- the environmental protection systems;
- stabilising processes in the waste; and
- occupational health and safety.

Positive list

Basically, a positive list must be restrictive, and it should address only a specific landfill. A waste type should be included on the positive list for a landfill only on the basis of an assessment of the anticipated short-term and long-term behaviour of the waste in relation to the relevant waste category as well as the

environmental protection systems at the landfill. This may be done by effecting a thorough testing of the waste. On this basis it must be possible to substantiate if the waste is behaving in accordance with the criteria for one of the waste categories.

The criteria determining whether or not a type of waste can be included on a positive list are as yet uncertain, and the scientific data basis is still vague. At the national level as well as at EU level work is ongoing to develop final criteria. Until such final criteria are available, the following guidelines can be applied:

Table 4.2
Waste categories

CRITERIA	CATEGORY I INERT WASTE	CATEGORY II MINERAL WASTE	CATEGORY III MIXED WASTES
Ignition loss	<2%	<5%	20% [1)]
Content of environmentally harmful substances	A	B	B
Quantification of potentially leachable matter	C	D	-
Knowledge of chemical composition	E	E	F
Expected leachate composition	G	H	H

1) For certain types of waste the ignition loss cannot be verified. Instead, an assessment in terms of volume must be made - related to the ignition loss. Desired organic half-life > 15 years.

A: Waste must not be capable of releasing (by evaporation, dissolution or leaching) significant quantities of environmentally harmful substances (neither organic nor inorganic).

B: Waste should not be capable of discharging (by evaporation, dissolution or leaching) significant quantities of environmentally harmful substances (neither organic nor inorganic).

C: Waste's quantitative content of potentially leachable pollutants and their identity should be known. Significant quantities of inorganic substances – including salts and trace elements - must not be leachable from the waste - in the short or long term.

D: Waste's quantitative content of potentially leachable pollutants and their identity should be known.

E: 95% of the total chemical composition of the waste should be known, and the chemical state in the short and the long term should be described, at least as a type (oxidising/reducing, pH/alkalinity).

F: 95% of the total chemical composition of a waste type should be capable of description, at least at waste fraction level. The chemical state of the fractions in the short and the long term should be capable of being described, at least as a type (oxidising/reducing, pH/alkalinity).

G: The composition of leachate should not at any time have any significant ecotoxicological effect, and it must be rendered probable that the leachate can at all times be accepted directly in the groundwater around the landfill.

H: It should be rendered probable that leachate can be accepted within a period of not more than 30 years in the groundwater around the landfill. Leachate may not exhibit any significant ecotoxicological effect that could constitute a risk to the leachate treatment system and the discharge therefrom.

Regarding the release and leaching of environmentally harmful substances, please refer to Annex A.

4.4 **Test levels**

Before any waste can be accepted for landfilling, it must be submitted to a hierarchical test system, consisting of three test levels:

Test level 1: Characterisation;
Test level 2: Compliance;
Test level 3: Identification.

The extent of testing is decreasing in relation to increased advance knowledge of the composition and properties of the waste.

Test level 1
Test level 1 is mandatory for the approval of a waste type for a positive list. Level 1 will be a comprehensive and documentative testing (cf. Annex A) and must provide the reference for tests at levels 2 and 3. In principle, it is to be performed only once for a waste type - or if the properties of the waste change.

Test level 2
Test level 2 is mandatory for the performance of checks to see if a waste type on a positive list (it assumes that level 1 has already been carried out) can be referred direct to the relevant acceptance criteria. Level 2 must be a comparatively simple test (cf. Annex A). Results should be capable of being related directly to the relevant acceptance criteria. Tests at this level should be carried out regularly. For the same waste type from the same supplier the test is performed, for example, once every year.

Test level 3
The purpose of test level 3 is to ensure that each load of waste received corresponds to the declaration (details from the waste producer). Level 3 must therefore be carried out on every load of waste accepted at landfills. In most cases this identification test can be confined to a visual inspection of the waste before and during unloading.

At the moment, development work is in progress under the auspices of CEN; the work aims to develop some specific tests and is expected to be completed in 1998.

4.5 Registration and acceptance procedures

Registration
Every load of waste transported to or removed from a landfill must be registered.
Pursuant to Statutory Order on Waste No. 299 of April 30, 1997, the registration is made under the ISAG (Information System for Waste and Recycling). This registration includes, for example: the source and waste type, and weight of aste.

As part of the self-control waste must also be registered according to one of the categories listed in sect. 4.2 and the level of testing performed.
Acceptance procedure
The decision as to whether a load of waste can be accepted is made on the basis of the procedure shown in Fig. 4.1 on the next page, and of the acceptance criteria listed in sect. 4.3 as well as of the test levels defined in sect.

4.4.

If the waste can be accepted for landfilling, the reception control will register the landfill unit to which the waste is assigned.*Rejection*

If the waste has to be rejected by the reception control, it must be assigned to another treatment facility in accordance with the assignment regulations of the municipality of origin. The authorities in the municipality of origin will be notified of the final treatment facility.

If, upon unloading, waste is not in accordance with the registration, the waste must be removed at the expense of the waste producer. If the waste is to be ssigned to other treatment, the authorities in the municipality will

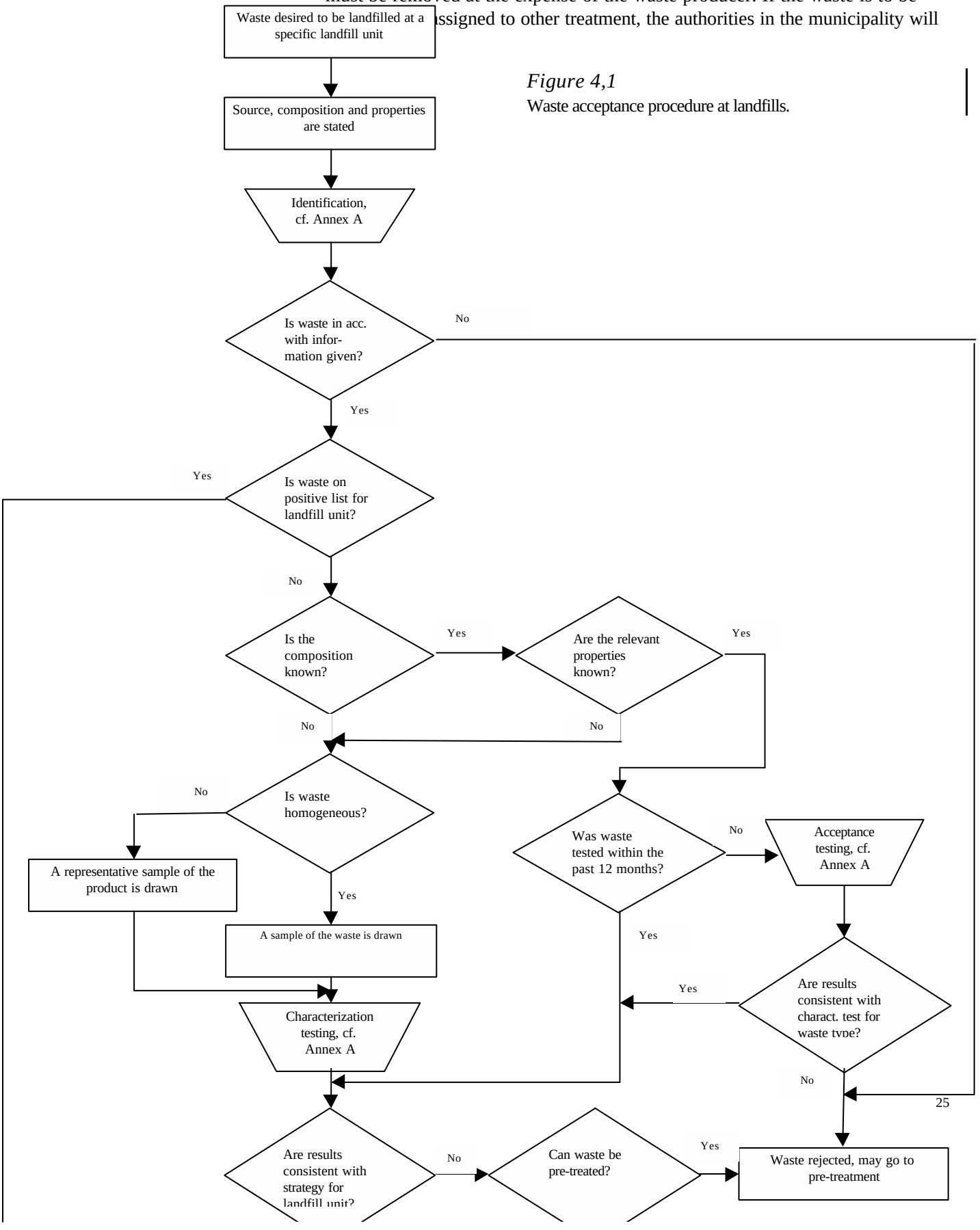

Figure 4,1

Waste acceptance procedure at landfills.

5 Preliminary Investigations

5.1 Definition and strategy

Any location of sites for landfills is made in connection with the regional planning of the counties.

Preliminary investigations are carried out at the site designated for the contemplated landfill. Such preliminary investigations must include a detailed description and assessment of all factors at the planned landfill which may affect the surrounding environment. The result of investigations forms the final basis for the assessment as to whether the relevant site is environmentally suited for landfilling the expected types of waste.

The result of the preliminary investigations must provide the basis for determination of the nature and extent of necessary environmental protection measures. Thus, the preliminary investigations must provide a basis for the establishment of separate environmental protection measures for each unit at the landfill.

The preliminary investigations must become part of the background documentation for the application for environmental permit. The preliminary investigations must therefore be sufficiently detailed to ensure that unanswered questions will not arise at a later stage which may have an impact on the environment, including the possibilities of transition to the exclusive use of passive environmental protection systems 30 years after landfilling has stopped.

5.2 Existing conditions

Existing conditions at the selected site are described, including the importance of the site in terms of natural and cultural patrimony as well as present use of the site. A description must be made of the observed above-ground structures and culture-historical monuments in the area. All possible and necessary measures relating to above-ground structures and culture-historical monuments must be described and evaluated.

The history of the area should be surveyed - including earlier activities, previous pollution and underground installations - by examining existing archive material.

Any known groundwater pollution upstream from the landfill should be evaluated. The data should be included when drawing up the monitoring and control programme.

5.3 Geology

The purpose of the geological investigations is:

- to assess the bearing capacity of the soil;
- to provide a basis for the hydrogeological evaluation (see sect. 5.4);
- to evaluate the suitability of naturally occurring clay for the landfill;
- to assess the occurrence of raw material resources and their suitability

for extraction.

Existing knowledge
Geological data may be obtained, for example, from the relevant county administration and are used for detailed planning of the preliminary investigations. Data exist in the form of geological basic data maps with selected bore holes, in the form of special soil type and thematic maps with or without cross sections, and as a computer database with various search facilities and presentations of data. Data are also available in the water abstraction plans drawn up by the regional authorities. As a basis for the selection of areas with special drinking water interests the regional authorities have drawn up groundwater protection maps. The maps are available in most counties via a geological information system (GIS). This information is used as basis for the assessment of the site and the need for additional investigations in the field.

Field investigations
Field investigations consist, primarily, of geophysical and drilling activities, including the drawing of soil type and groundwater samples, the extent of which depends on the local geological conditions.

Assuming that the selected site has a simple geological structure, the extent of geophysical investigations and drilling programme should be decided on the basis of available knowledge of the geology of the area.

At sites *without interbedded clay strata* or other low-permeable strata between the future landfill and the primary aquifer, the geology can be examined solely by means of a drilling programme.

At sites *with interbedded clay strata* or other low-permeable strata between the future landfill and the primary aquifer, geophysical - notably geoelectrical - measurements should be carried out to determine the extent and thickness of the low-permeable strata. This mapping should then be supplemented by a drilling programme designed on the basis of existing knowledge and the result of the geophysical investigations. The geophysical investigations are used for:

- description of the homogeneity/heterogeneity of the area;
- assessment of the extent of low-permeable strata;
- design of the subsequent drilling programme; and
- assessment as to whether the site is still considered suitable for a landfill.

For further details of the geophysics, see Note[1]. Reference is also made to the soil and groundwater project from the Danish Environmental Protection

[1] A geophysical measuring programme can consist of a combination of vertical geoelectrical sounding and geoelectrical line profile measurements. The former should be made in a grid with a spacing of about 100 metres and a maximum current electrode spacing of four times the depth to the lower limit of the clay/low-permeable stratum.

One or two vertical geoelectrical soundings are made close to existing, geologically well-described bore holes for calibration and interpretation of the geophysical measurements.

The geoelectrical line profile measurements must be appropriately placed in relation to the soundings. The direction should be chosen so that it runs parallel, as far as possible, with the strike of the clay/low-permeable stratum. The distance between the current electrodes should be chosen as at least twice the depth to the centre of the low-permeable stratum. If a direction is chosen other than parallel with the gradient of the stratum, this will render the interpretation of measurements difficult - because the geophysical laws assume homogeneous and parallel strata.

The results of the measurements are produced as index maps and geophysical cross sections of the area investigated. The results should show the possible stratigraphic sequences and, as isoline and isopach maps, the extent and thickness of the low-permeable strata.

Agency's Guidelines No. 11/1995: "Monitoring of groundwater based on new geophysical measuring methods".

Drillings
Drillings are carried out as part of the geological mapping and as part of the hydrogeological mapping. If, at the individual drilling, the drill has penetrated low-permeable strata, the bore hole must be sealed - for example, with bentonite - at the level of the low-permeable strata to prevent leakage from the landfill via bore holes. If there are no low-permeable strata, the material which has been drilled out will be returned to the hole.

If a geophysical mapping has been carried out, one or two drillings should be performed for the purpose of checking the interpretation of the geophysical measurements. Thereupon, a drilling programme should be carried out in a grid covering the various types of stratigraphic sequence as they appear from the database information and the geophysical mapping.

Where no geophysical mapping has been carried out, a drilling programme should be performed in a grid with a spacing of some 100 metres - unless the geological data indicate that another grid spacing *must* be selected.

Regarding the carrying-out of drillings please refer to Statutory Order of the Ministry of Environment No. 4 of January 4, 1980, and the Danish Environmental Protection Agency's Circular of February 28, 1980, on the carrying-out of drillings for groundwater. Reference is also made to DS 441 and DS 442 on non-common and common water supply systems. The Danish Environmental Protection Agency plans to publish a Statutory Order in 1997 on the carrying-out of onshore drillings.

5.4 **Hydrogeology**

The purposes of the hydrogeological investigations are:

- to describe aquifers that are being used or are suitable for water abstraction;
- to describe the routes of the groundwater between and within the individual aquifers and to wetlands;
- to describe the suitability of low-permeable strata as natural liners;
- to describe the water quality in each aquifer;
- to describe the possibility of remedial actions, if any; and
- to determine the location of groundwater monitoring bore holes.

Existing knowledge
Hydrogeological data are gathered from the geological databases, from the relevant county administration, as well as data from the regional water abstraction plans. Data are stored in the form of computer databases as geological database maps and as thematic maps describing the transmissivity and potential of selected aquifers.

In addition, there is a chemical database describing the chemical composition of the individual groundwater aquifers. For a number of areas these data are also presented in the form of groundwater-chemical maps.

Information on groundwater pollution deriving from landfills and contaminated sites is gathered from registers kept by regional and local authorities. This information is relevant to the assessment of the present chemical background level in aquifers associated with the landfill.

Field investigations
Existing knowledge and the result of the geological investigations are used as planning basis for the field investigations.

The field investigations may include the location of existing bore holes, new drillings, and various forms of hydraulic tests.

The extent and nature of drillings and hydraulic tests depend on existing data on the geological structure of the area and the occurrence of aquifers.

Investigations will normally be more comprehensive when the area holds several aquifers separated by low-permeable strata.

The main components of the investigation programme can be described as in Table 5.1 depending on the prevailing local conditions.

Table 5.1
Extent of field investigations in relation to local conditions.

	LOCAL CONDITIONS	
INVESTIGATION	ONE LOW-PERMEABLE STRATA	TWO OR MORE AQUIFERS SEPARATED BY LOW-PERMEABLE STRATA
BORE HOLES	Few, with a screen in the same aquifer	Several, drilled to varying depths ending with a screen in the various aquifers
HYDRAULIC TESTS	Measurements of potential in one aquifer Several brief pumping tests/ slug tests with or without observation of water table in the monitoring well	Measurements of potential in two or more aquifers Few, long-lasting pumping tests with observation of pressure impact in the monitoring well
TEST OF LEAKAGE THROUGH LOW-PERMEABLE STRATA	None	One or more - based on pumping tests and the geological investigations
CHEMICAL TEST	Few water samples	Several water samples to assess the individual aquifers
GROUNDWATER MODELS	Limited need for hydrogeological models	Pronounced need for hydrogeological models

Bore holes
Cased bore holes are made to the secondary and primary aquifers in the area. After the drilling work is complete, each aquifer must have a minimum of three bore holes with screens. If there are existing bore holes in the immediate vicinity of the area under review, the drilling work can be reduced correspondingly - provided that the existing bore holes are well described. When installing screens in bore holes that penetrate low-permeable strata, the holes are sealed with bentonite (a minimum of 1 metre of bentonite) at the level of these strata. After completing the installation of screens, the hole should be pumped clean. During this procedure the drawdown and the output of water in the hole should be

recorded. This registration may be used for a preliminary assessment of the hydraulic conductivity of each aquifer - and thus for the planning of longer-lasting, subsequent pumping tests.

Core samples from the drilling work should be drawn and described as specified under the geological drilling work in para. 5.3.1.

Potentials
A minimum of three bore holes from each aquifer in the area should be included in simultaneous probing of the water table. A minimum of three bore holes in each aquifer is necessary to enable a determination of the direction of gradient of the water table - and thereby the direction of flow of the water under the landfill.

The results of the probing should be produced in the form of a potential map for each aquifer.

Water table/pressure differentials between the individual aquifers should be used for an assessment of the risk of leachate infiltration from the landfill to secondary as well as primary aquifers. If the aquifer just beneath the landfill has a higher water table/pressure level than the pressure level in deeper aquifers, there is an increased risk of downward leachate infiltration.

The knowledge of flow direction - combined with the knowledge of flow rates as determined by hydraulic tests - should be used for the location of groundwater monitoring and control wells upstream and downstream from the landfill.

Hydraulic tests
Hydraulic tests should be performed in the screened bore holes to determine the hydraulic parameters of the aquifers. These parameters are: aquifer geometry, hydraulic conductivity, porosity, and aquifer coefficient. For further details of hydraulic tests, see Note[2].

Water quality in aquifer
In order to make a qualified assessment of any possibility of utilising the various aquifers under and around the landfill, the groundwater quality of each significant aquifer should be examined. Chemical parameters that should be included in this analysis are stated in the analysis programme for groundwater in Table 5.2.

If there is evidence of upstream groundwater pollution close by, the analysis programme should be adapted accordingly.

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[2] Unconfined aquifers should be tested with brief pumping tests lasting from 3 to 5 hours. The pumping test is performed at maximum constant capacity as determined by the pumpings undertaken earlier (to clean the holes). Pumping tests are performed in two or three bore holes covering the area under review. If it is possible to include monitoring wells very close to the bore holes, any changes in the water table should be monitored to determine the specific capacity of the aquifer. If this is not possible, the geological test description must be used for an assessment of the specific capacity.

Confined aquifers should be investigated by means of longer-lasting pumping tests in a single hole, preferably in the centre of the area under review, with monitoring of the pressure impact in at least two monitoring wells located in different directions and at different distances from the bore hole. The pumping test should last from one to about three weeks, because the pumping test should continue until the data basis for the aquifer geometry and the assessment of aquifer and leakage coefficients is complete. The final hydraulic parameter, in particular, is important for the assessment of any active technical measures that should be included in the final design of the landfill.

In addition, the hydraulic parameters should be used for the design of the necessary monitoring programme.

Water abstraction
Existing and contemplated water abstractions should be mapped, normally within a distance of about 2 kilometres from the landfill. This distance should be increased in the groundwater downstream, and reduced upstream from the landfill. The mapping should include non-common supplies, common water supply facilities, and field watering systems. The result of the hydrogeological investigation forms the basis for the assessment of the risk of any impact on these water supply facilities.

The risk of affecting the groundwater (water supply) and/or recipients is assessed on the basis of the mapped flow directions , hydraulic conductivity in each aquifer, and the risk of leakage among the individual aquifers.

The risk assessment can be made in accordance with the guidelines described in the Danish Environmental Protection Agency's Guidelines: "Cleaning Up Contaminated Sites", to be published shortly.

If it is estimated that there might be a risk, further investigations are called for. If these investigations continue to show an unacceptable risk - or if no supplementary investigations are made - no landfill should be located on the relevant site.

5.4.1 **Groundwater monitoring**

Purpose
The purpose of groundwater monitoring around a future landfill is to select bore holes for the subsequent groundwater control as well as to determine the background levels for the relevant parameters in relation to the groundwater control to be carried out after commissioning of the landfill.

Groundwater monitoring must thus be carried out before landfilling starts.

Monitoring wells
The number, location and development of monitoring wells depend, primarily, on the number of aquifers near the landfill.

The monitoring wells must be capable of monitoring:

- the groundwater flow (direction and rate) in the primary and secondary aquifers below and around the landfill; and
- the natural groundwater-chemical state upstream and downstream from and below the landfill.

Provided that the hydrogeology around the landfill is simple, the primary and secondary aquifers may be monitored by means of at least three screened bore holes in each aquifer. The flow direction in each aquifer has been determined by the preliminary hydrogeological investigations. The basis for the location of monitoring wells should be that at least one well is placed immediately upstream and at least two immediately downstream from the landfill depending on the hydrogeological conditions. If there are more aquifers, this procedure is repeated for the other aquifers.

The location of downstream wells in the aquifer just beneath the landfill is selected on the basis of an estimate of the prevailing flow-dynamics. Any impact on the deeper aquifers will not necessarily be evident immediately downstream from the landfill. Installing screens in the individual wells in more

than one aquifer is not recommended; experience shows that this involves a high risk of leakage among the aquifers via the wells.

Increasing complexity of the hydrogeology around the landfill will increase the need for additional monitoring wells.

The wells for the primary as well as any secondary aquifers are normally provided with a 5-metre screen installed in the top part of each aquifer. The wells are to be carefully closed with a clay seal around the casing above the screened interval, so that pollution from above along the casing is avoided. If there are low-permeable strata above the screened section, these strata are provided with bentonite seals.

The wells are pumped clean after the installation of screens, so that they are ready for subsequent water sampling for chemical analyses. The pumping procedures should be the same as those for water supply bore holes.

Monitoring well are used for control wells after the landfill starts operation.

Regarding the carrying-out of bore holes please refer to Statutory Order of the Ministry of Environment No. 4 of January 4, 1980, and circular from the Danish Environmental Protection Agency of February 28, 1980, on the carrying-out of drilling for groundwater. Reference can also be made to DS 441 and DS 442 on non-common and common water supply systems. The Danish Environmental Protection Agency expects to publish a Statutory Order in 1997 on the carrying-out of onshore drillings.

Sampling
Monitoring wells are pre-pumped prior to sampling by pumping, as a minimum, a quantity of water corresponding to about ten times the volume of the bore hole and the gravel volume. The pump is placed at the centre of the screened interval, so that as far as possible the pumping represents the screened interval.

See also Guidelines from the Danish Environmental Protection Agency No. 3/1992: ”General Sector Specific Guidelines for Contaminated Sites”.

Analysis programme
The starting point for the selection of analysis parameters for groundwater monitoring in a future landfill should be:

- The results of the preliminary investigations; and
- the expected nature and composition of the waste to be landfilled.

Table 5.2 shows suggested analysis parameters for groundwater monitoring for future landfills intended for landfilling of, respectively, mixed wastes, mineral waste and inert waste.

In the case of mono-landfills the analysis programme should be more specifically oriented in terms of selection of measuring parameters based on leaching tests.

Frequency of analyses
It is proposed that groundwater monitoring be carried out at intervals of six to twelve months between analyses. As a minimum the monitoring should include

three series of analyses. The monitoring period should be at least two years. The final monitoring analysis should be carried out within one year before commissioning of the landfill.

Analysis laboratory
Analyses must be carried out in laboratories that are accredited for the relevant analysis. Any use of non-accredited laboratories requires acceptance by the inspection authority.

Table 5.2
Analysis parameters, groundwater monitoring

PARAMETER	LANDFILL UNIT		
	INERT WASTE*	MINERAL WASTE	MIXED WASTES
pH	x	x	x
Conductivity	x	x	x
Dry matter	x	x	x
BI_5			x
NVOC	x	x	x
AOX		x	x
GC-FID screening			x
Total N	x	x	x
Ammonium-N			x
Chloride	x	x	x
Sulphate	x	x	x
Sulphide	x	x	x
Sodium	x	x	x
Calcium	x	x	x
Iron		x	x
Potassium		x	
Lead		x	x
Cadmium		x	x
Copper		x	x
Chromium		x	x
Nickel		x	x

NVOC = Non-Volatile Organic Carbon
AOX = Adsorbable Organically Bound Halogen
GC-FID screening = Screening by means of gas chromatography for contents of extractable, organic substances, including solvents and oil products
* = Where the composition of leachate can be checked, cf. sect. 3.2.

5.5 Surface Water

The impact of the landfill on surface water is made up, partly, of an impact from treated leachate - no matter if the leachate is treated locally or is removed to another treatment plant - and partly of the impact from paved areas and cut-off drains, if any, around the landfill.

5.5.1 Leachate

Based on the quantity and composition of leachate possibilities of treatment, disposal and environmental impacts must be assessed.

The assessment should include:

- The capacity and suitability of nearby treatment plan for the treatment of leachate, including the sensitivity of the treatment plant to peak loads from the addition of leachate and the resulting content of heavy metals

in the sludge produced.

- The prospects of disposal of leachate by tank lorry and/or sewer system.
- The treatment effect on leachate by treatment in a municipal treatment plant, and the effects of alternative treatment methods and/or direct discharge.
- Technico-economic assessment of the need for expansion of any treatment plant (such as the need for receiving and feeder tanks as well as adaptation of the treatment method).

If leachate is treated separately in an on-site facility, the treatment requirements should be determined along the lines of other wastewater treatment plants, having regard to the objective for the receiving wetland.

For landfill units established with reduced or exclusively passive environmental protection systems the expected impact from the leachate must be described. The description must specify where discharge takes place.

5.5.2 **Paved areas and cut-off drains**

Lakes, ditches and watercourses near the landfill must be mapped out.

The prospects of draining surface water from paved areas and cut-off drains around the landfill should be assessed, having regard to the objective for the receiving wetland.

The need for any technical measures (equalisation basins, oil separators, sand traps, etc.) should be assessed.

5.6 **Future conditions**

5.6.1 **Traffic**

The impact of the landfill on the traffic load and traffic safety of the area should be assessed in the light of the volume of waste likely to be transported to the landfill. Seasonal fluctuations (periods of peak load) as well as daily variations should be included in this assessment.

Access conditions to the landfill should be planned in such a manner that vehicles follow routes that provide the highest degree of traffic safety and the lowest degree of nuisance - especially in the form of noise and dust - for built-up areas in the vicinity (residential, commercial and industrial buildings).

5.6.2 **Noise**

In the light of initial considerations concerning the layout and operation of the landfill, cf. sect. 5.6, a calculation should be made of the expected noise level from the landfill. The calculated noise level should become part of the basis for an application for environmental permit. The noise calculation should be made on the basis of:

- The expected number of coming and going vehicles per day.
- The number of unloading operations per day.
- The expected number of stationary and rolling equipment on the site.
- The number of operating hours per day for each piece of equipment.

In the calculation, the topography around the landfill shall be taken into consideration.

The calculations should be carried out in accordance with the Danish Environmental Protection Agency's Guidelines No. 5/1993: "Calculation of External Noise from Enterprises".

The need for and possibilities of noise-reducing measures, such as alternative technology, noise barriers, and the planning of operation, must be examined.

5.6.3 **Future land use**

The future land use for a landfill is laid down in a local plan for the area.

The landscape can affect the layout and filling rate of the landfill and must therefore already be part of the preliminary investigations for the landfill.

The factors outlined below should be incorporated, as a minimum, into the considerations regarding the future landscape.

Filling heights
The considerations regarding the maximum average filling height should include considerations regarding the leaching behaviour of the waste. This means that the filling height must be based on the demand that leachate from the waste must be acceptable in the environment when the active systems of the landfill must be abandoned.

In view of planning and the fact that there are limited possibilities for the location of new landfills, there should not be large areas of the landfill where the filling height is less than 5-7 metres.

Furthermore, when landscaping the site, the location of leachate collection wells on the landfill area should be given special consideration. Such wells should be placed where the filling height is lowest, because great filling heights can prevent the possibility of maintaining and inspecting the wells and/or their installations.

Stability
Future settlement of the landfilled waste must be allowed for, so that unintended depressions in the final landscape are avoided.

In order to avoid the risk of erosion no restored surfaces should have a gradient steeper than 1:3.

Drainage
The natural run-off of surface water must ensure that there will be no areas within the landfill with increased infiltration of water and a resulting increase in the production of leachate.

5.7 **Draft Design**

Draft Design
The draft design for a landfill should be based on the preliminary investigations performed as described in sects. 5.1-5.5 as well as the layout described in Chapter 6.

As a minimum the draft design must contain a description of the following subjects:

- The layout of the site;
- the need for active and passive environmental protection systems;
- the design of active and passive environmental protection components; and
- the total landfill capacity and the expected filling rate.

Environmental description and assessment
The draft design is used for an environmental description and assessment of the landfill and the site on which it is to be located. This description and assessment of the landfill will form the final basis for the application for environmental permit.

6 Layout

6.1 Definition and Strategy

A landfill must be laid out in an environmentally sound manner. The layout must allow for the protection of groundwater, recipients, soil and air.

Landfills are subdivided into units. This makes it possible to landfill waste in units corresponding to the nature of the waste. In practice most landfills could be subdivided as shown in Tables 3.1 and 3.2.

In order to limit the open landfill and liner surface, each landfill unit must be divided into smaller cells. This will minimise a number of nuisances such as the generation of leachate, odour, airborne waste, etc. At the same time it results in a more well-arranged facility in terms of operation, and it can be established in sections gradually as the landfill is being filled.

Basically all leachate from all units of the landfill must be collected and treated. The landfill units must therefore be laid out with active environmental protection systems (components) that provide optimum environmental protection throughout the active period of the landfill.

The landfill units may be designed for specific types of waste with reduced active - or exclusively passive - environmental protection systems. This calls for prior assessment of the leaching behaviour for the types of waste to be received. The advance assessment must be capable of showing that leachate from the site in question is immediately acceptable in the groundwater around the landfill facility. Furthermore, the preliminary investigations for the area must include an overall assessment of the impact on the environment which shows that it is acceptable.

6.2 Active and Passive Environmental Protection Systems

Active and/or passive environmental protection systems consist of a number of components determined on the basis of the preliminary investigations for the proposed area.

6.2.1 Active Environmental Protection Systems

Active environmental protection systems are those systems which provide complete protection of the environment against the effects of pollution from the landfilled waste.

Active environmental protection systems are characterised by requiring an active effort in the form of control, inspection and/or maintenance.

For active environmental protection systems that cannot be maintained (e.g., because access to these components is unrealistic) special documentation is required for their durability. Furthermore, the requirements for control of the design and construction of these components are more stringent, cf. Table 6.1.

For active environmental protection systems that *can* be maintained and which

are capable of being inspected, the requirements for control of the design and construction may be normal or moderate, cf. Table 6.1 below.

Table 6.1
Examples of active systems and requirements for quality assurance of these.

ACTIVE ELEMENTS	THE ACTIVE EFFORT	PROSPECTS OF MAINTENANCE	QUALITY CONTROL	
			Design	Constr'n
Liner	Control of groundwater/ surface water	Unfeasible in practice	Stringent	Stringent
Leachate collect. (drains)	Inspection and control of flow	Partly accessible	Stringent	Normal
Leachate pumps, etc.	Inspection and maintenance of leachate pumps, etc.	Accessible and feasible	Normal	Normal
Pre-treatment facility	Maintenance of the facility and inspection of components of the facility. Control of discharge	Accessible and feasible	Stringent	Normal
Gas venting	Inspection of the system and maintenance of the components	Partly accessible	Normal	Normal/ moderate
Fences	Maintenance	Easily accessible	Moderate	Moderate

Active environmental protection systems must be operational throughout the active phase of the landfill. The active phase is the phase where it is necessary to handle pollutants from the landfilled waste. The criteria that govern when a landfill unit can pass from the active to the passive phase are specified in sect. 11.8.

6.2.2 Passive environmental protection systems

Passive environmental protection systems are those systems which shield the landfilled waste from the surroundings. Where passive systems are used exclusively, the environmental protection consists only of knowledge of the waste landfilled.

Passive environmental protection systems differ from active systems in that these systems can always be left to themselves and, in principle, require no control, inspection or maintenance to meet the functional requirements.

Examples of passive components are: embankments built around the landfill, perimeter and surface drains, final cover, infiltration and percolation systems, and permeable and low-permeable bottom.

6.2.3 Transition from active to passive environmental protection systems

The criteria determining when a landfill unit may pass from the active to the passive phase appear from sect. 11.8. When these criteria are fulfilled, it must be possible to leave the landfill facility to itself. This implies that all active environmental protection systems can be abandoned, and the leachate generated can be accepted directly in the environment.

Therefore, already in connection with the design of the landfill, consideration must be given to how leachate can percolate to the surroundings from each landfill unit by an even distribution - without any surface run-off of leachate, and without leachate from different landfill units being inappropriately mixed.

6.3 General Layout

Every landfill includes a number of layout components which are the same regardless of the size and nature of the landfill. These are specified in the following.

6.3.1 Reception area

The reception area should be paved and in most cases placed in a central location in the landfill just next to the access road. From the reception area it should be possible to monitor each load of waste arriving in or leaving the landfill facility.

The reception area should, as a minimum, include the following facilities:

Control building
The control building should be located, designed, and equipped so that all control and monitoring of the landfill can be carried out from it. This includes waste control with a view of the weigh-bridge, electronic monitoring of leachate pumps, etc., as well as monitoring of coming and going vehicles.

Weigh-bridge
In the reception area there should be at least one weigh-bridge for the weighing of waste (in- and out-going); the weigh-bridge should have facilities for electronic registration.

Wash-down facilities
There must be access to wash-down facilities for vehicles where there is a wish/requirement for cleaning before they leave the landfill, so that nearby roads are not fouled.

Staff buildings
Staff buildings should include locker rooms, rooms for personal hygiene and lounges, etc. The premises must be laid out so as to comply with Statutory Order of the Ministry of Labour No. 1163 of December 16, 1992.

Drainage
The reception area should have its own drainage system. All drains from paved areas in the reception area should pass an oil separator. In general, all drainage must comply with applicable drainage regulations.

6.3.2 Internal road network

Internal roads within the landfill which are intended to be used over a considerable period of time should be paved. Special compactor roads should be established so that there is no compactor traffic on roads for other traffic.

6.3.3 Landfill area

The landfill area is subdivided as required into a number of landfill units as defined in Chapter 3. Each landfill unit should be designed with the necessary

active and/or passive environmental protection systems depending on the nature of the landfill unit and the results of the preliminary investigations.

Landfill unit
Each landfill unit at a landfill must be clearly delimited, and plans for this delimitation should exist before it is established. In most cases the delimitation between two landfill units can be made in the form of an embankment. Where the mixing of leachate from two different landfill units is unacceptable, the height of the embankment or other low-permeable separation must be increased gradually as the landfill units are filled.

Cells
The landfill units should be divided into cells so as to limit the open landfill surface - and thereby the generation of leachate - as well as to optimise operations in the landfill units.

The size of the cells is determined so that the volume of waste added to each unit can cover the liner surface with a least two metres of waste during the first twelve months of operation of the landfill unit. In practice, no cell should exceed an area of 2-3 hectares.

The cells can thus be established as and when the need arises.

Environmental protection systems
Each cell is established with environmental protection systems such as:

- Liner systems;
- leachate collection systems;
- drains and ditches for surface water run-off; and
- embankments.

Liner systems
Each cell is established with a liner system that meets the requirements for the landfill unit. See also Chapter 3: ”Definition of Landfills” and Chapter 7: ”Liner Systems”.

Leachate collection systems
Each cell is laid out with side drains, main drains and a leachate collection well which allows the drawing of leachate samples. Facilities for checking the leachate level of each cell should also be established. See also Chapter 8: ”Leachate Collection Systems”.

Drains and ditches
If there is a risk of surface water infiltration into the landfill from the surroundings, perimeter drains and ditches should be established. Discharge from these can occur to the nearest wetland or through fascines to the groundwater - if it is certain that the water is not polluted from the landfill.

Embankments
The delimitation of a cell is made in the form of a liner-covered embankment not less than one metre high. The height of the embankment is intended to ensure that leachate will at no time flow outside the liner-covered areas.

6.3.4 **Shielding from the surroundings**

Seen from the surroundings the landfill should always appear aesthetically acceptable. The landfill should therefore be shielded from the surroundings so that there is no direct view into it, and so that no waste lies about in the area surrounding the landfill.

Embankments
Embankments towards the surroundings should normally be placed along the perimeter of the landfill. The embankments should be designed so that they become part of the future landscape, and so as to avoid erosion.

Normally, the embankments will ensure that the working face is cut off from the surroundings. Furthermore, a direct view of the landfill is prevented. This determines the height of the embankments, but under normal circumstances they should not be less than three metres above the liner surface, whereupon they are extended gradually as the landfill is filled - so that they fulfil their purpose at all times.

Fences
A fence should be erected around the total landfill in order to prevent un-controlled unloading of waste at the landfill, and to catch any wind-borne waste. Fences should be placed high and freely - such as at the top of surrounding embankments. The fences should be about two metres high and should be equipped with lockable gates at all entrances. During the filling of the landfill the fence must, if necessary, be moved so that it fulfils its purpose at all times.

Vegetation
So as to achieve a shielding effect as well as to allow the landfill to appear in an aesthetically acceptable manner, vegetation should be made around the bounding embankments of the landfill. Because new plants will not have the desired effect, the plants used should be of some age.

6.3.5. **Occupational health and safety**

The landfill must be sound in terms of occupational health and safety. Please refer to the rules of the Ministry of Labour/the Directorate of Labour Inspection applying at any time.

In particular, attention is drawn to the following regulations:

- Statutory Order of the Ministry of Labour No. 501 of October 5, 1978, on the Duties of Engineers and Consultants, etc., pursuant to the Working Environment Act;
- Statutory Order of the Ministry of Labour No. 1163 of December 16, 1992, on the Layout of Permanent Work-sites;
- Statutory Order of the Ministry of Labour No. 1182 of December 18, 1992, on the Execution of the Work; and
- Statutory Order of the Directorate of National Labour Inspection No. 473 of October 7, 1983, on Sewage Work, etc.

7 Liner Systems

7.1 Definition and Strategy

Liner systems are used where leachate from a landfill must be collected in order to ensure that soil, groundwater and surface water are not polluted by the leachate.

Basically, a liner system must be impermeable and provide optimum environmental protection throughout the active phase of the landfill. With that in mind every liner system for a landfill should be designed as a composite liner system or another bottom design which provides the same or better environmental protection. A composite liner system consists of a primary and a secondary liner in direct contact.

Another bottom design with similar environmental protection that might be considered is the use of hydraulic barriers. These must be regarded as site specific cases and call for separate assessment; therefore, they are not further described in these Guidelines.

7.2 Types of Liner

The material for a liner must be capable of withstanding the physical impacts to which the liner is exposed during the construction process as well as physical and chemical impacts during the active phase of the landfill. Table 7.1 shows the types of liner that may be used in a liner system.

Table 7.1
Summary of the types of liner that may be used in a liner system with specification of requirements, control, execution and quality assurance.

TYPES OF LINER	REQUIRE-MENTS	CONTROL PARAMETER	EXE-CUTION	CONTROL LEVEL
Clay liners * In-situ liners * Installed liners	L > 14% L_p > 5% k < 10^{-10} m/s (by lab test) 95% Standard Proctor Thickness of layer: min. 2m Thickness of layer: min. 0.5m	Permeability co-efficient Clay content Plasticity index Standard Proctor Lime content	cf. DS/R 466	Design: normal Base: stringent Execution: stringent Protection layer: stringent
Polymeric membrane liners	cf. DS/R 466 Thickness of layer: min. 1mm Few joints	cf. DS/R 466 Long-term resis-tance to chemical and biological impacts	cf. DS/R 466	Design: normal Base: stringent Execution: stringent Protection layer: stringent
Bentonite liners	cf. Annex B[1)]	cf. Annex B[1)] Long-term resis-tance to chemical and biological envi-ronmental impacts	Appears from detailed in-stallation manual	Design: stringent Base: stringent Execution: stringent Protection layer: stringent
Composite liners	Minimum: as each of the liners included, cf. above	Minimum: as each of the liners in-cluded, cf. above	Appears from detailed in-stallation manual	Design: stringent Base: stringent Execution: stringent Protection layer: stringent

1) : Please refer to Annex B until a revised edition of DS/R 466 includes bentonite liners.
L: Clay rate.
L_p: Plasticity index.
k: Permeability coefficient (saturated hydraulic conductivity).

7.2.1 **Clay liners**

Clay liners are low-permeable and cannot provide 100 per cent assurance against percolation. However, if a suitable material is chosen and the work is carried out meticulously, percolation can be reduced to a minimum. There are two types of clay liner: installed and in-situ liners. In-situ liners are in the form of natural deposits of clay. Installed liners are composed of two or more layers of homogeneous clay spread on the landfill area.

For requirements as to properties, control of materials, and the execution of

clay liners, reference in general terms is made to the revised edition of DS/R 466.

The recommended layer thickness and quality assurance are specified in Table 7.1, which also contains a summary of the most important requirements and material controls.

7.2.2 **Polymeric membrane liners**

Plastic and rubber liners (polymeric membrane liners) must be chosen and installed so that they can resist the physical and chemical impacts to which they will be exposed during the construction work and throughout the active period of the landfill.

For a polymeric membrane liner to be selected for the relevant purpose, it must meet a number of material-specific requirements. These requirements will appear from the revised edition of DS/R 466; therefore, reference is made only to that document.

Polymeric membrane liners must have a minimum thickness of 1.0mm, and the number of joints to be made in the field should be as low as possible.

Material control
The long-term resistance of polymeric membrane liners to the chemical and biological impacts that apply to a landfill must be documented either by simulation laboratory tests or by producing material based on experience.

In addition, there must be documentation for the requirements for materials contained in the revised edition of DS/R 466.

Execution
Polymeric membrane liners should be installed and fitted so that they are protected against impacts that could lead to puncture and reduced resistance. The base for polymeric liners should be pre-treated so that it is level and free from stones and subsidence, cf. DS/R 466.

Welds and joints are the weakest points. The number of welds made in the field must therefore be as low as possible. Any welding must be carried out by plastics welders who have attended and passed one of the courses approved by the Directorate General for Employment Placement and Vocational Training within the area. The execution control must be stringent.

7.2.3 **Bentonite liners**

A bentonite liner may consist *either* of sodium or calcium bentonite in the form of granulates or powder laid out between two geotextiles, *or* of loose bentonite laid out with a spreader and ploughed down into an underlying layer of sand. Such a liner should contain about 10 per cent bentonite by weight.

In terms of installation it is more difficult to produce a uniform liner surface when using loose bentonite than in the case of finished liners (bentonite mats/carpets). Also, more tests are required of the permeability coefficient of the installed liner than in the case of bentonite mats/carpets.

For a bentonite liner to be used in a landfill, it must meet a number of material-

specific requirements. These requirements will appear from Annex B and the revised edition of DS/R 466.

Material control
The long-term resistance (especially the chemical stability of the contents of sodium or calcium) to the chemical and biological impacts that apply to a landfill must be documented either by simulation laboratory tests or by producing material based on experience.

In addition, there must be documentation as specified in Annex B and in DS/R 466 (after revision).

Execution
The supplier of the bentonite liner should prepare a detailed installation manual. The installation manual should also include a description showing how the base and the protective layer (drainage layer, cf. Chapter 8) for the liner are to be prepared. When the revision of DS/R 466 comes out, the installation manual should adhere to these instructions.

The installation manual should include a description showing how the liner is connected tightly to pipes, wells, joints, etc.

7.2.4 **Composite liners**

A composite liner consists of two types of liner joined together in production. The composite liner must be made of materials that meet the requirements of DS/R 466 in terms of tightness, physical strength, as well as chemical and biological resistance.

When producing and installing a composite liner it must be ensured that the permeability coefficient does not become inferior to the lowest permeability coefficient for the liners included.

A handling and installation guide from the manufacturer must be available.

Material control
Controls must be made to ensure that the liner materials included will not affect each other in such a manner that the composite liner fails to meet the requirements listed in DS/R 466.

Execution
The supplier of the composite liner should have prepared a detailed installation manual. The installation manual should also include a description showing how the base and the protective layer for the liner are to be prepared.

The installation manual should include a description showing how the liner is connected tightly to pipes, wells, joints, etc.

7.3 **Choice of Composite Liner Systems**

It is assumed in the following evaluations of a composite liner system that the liners it consists of - the primary as well as the secondary liner - meet the requirements listed for the individual liners in sect. 7.2.

Clay liners
In-situ clay liners can function in a liner system only as secondary liner. The primary liner can be a polymeric membrane liner, a bentonite liner, or a composite liner.

An installed clay liner will not be capable of functioning as primary liner if the secondary liner is an in-situ clay liner.

If an installed clay liner is to be used in a composite liner system together with a polymeric membrane liner, a bentonite liner, or a composite liner, it *must* be used as secondary liner and one of the others as the primary one. The reason is the substantial mechanical treatment during the installation of the clay liner.

Polymeric membrane liners
Polymeric membrane liners may be used as primary liner in a composite liner system. Clay liners and bentonite liners should be used as secondary liner.

Bentonite liners
Bentonite liners in a composite liner system can act as primary as well as secondary liners. Bentonite liners will often be used as primary liner in connection with clay liners and as secondary liner in connection with polymeric liners and composite liners.

Composite Liners
As described in para. 7.2.4., composite liners consist of two types of liner joined together by the manufacturer. If each of the liners the product consists of meets the requirements described in 7.2 above, it can be used as a composite liner system.

If one of the liners in the product fails to meet the requirement, or if some of the properties have been altered by the joining, a composite liner can be used as primary or secondary liner.

Protective layer
As soon as a composite liner system has been installed, the liner must be covered with a protective layer consisting of drainage gravel that meets the criteria in the most recent edition of DS/R 466. This layer will then act as the drainage gravel layer of the landfill unit.

The spreading of the protective layer should be done with caution. *No* traffic may occur direct on the liner. It may thus be necessary to take special precautions - such as in the form of installation of a protective layer of considerable thickness during the construction works - where traffic is un-avoidable. A separate description of this must be available before the protective layer is laid out.

7.4 **Execution**

7.4.1 **Bottom and side liners**

Bottom and side liners for a landfill should consist of identical composite liner systems. Therefore, when choosing composite liner systems, allowance should be made for the location and design of the landfill.

If the landfill is placed in a hole or an excavation, it is necessary to ensure that the slope angle is not excessive. The slope angle should be determined on the

basis of Skempton's formula, cf. DS/R 466. Steps must also be taken to ensure that the liners in a liner system have mutually satisfactory friction properties and are stable both in their dry and wet states, so that no tensile stress will occur in the liner.

Side liners
An effort should be made to ensure that the side liner has as few welds/ joints as possible.

7.4.2 **Liner subgrade**

Liner subgrade
The subgrade for the liner system shall be natural deposits and/or backfilling with properties ensuring that:

- no differential settlement arises which is greater, within a 4-metre straightedge, than the requirements for evenness of the finished liner surface;
- within the service life of the landfill no settlement or deformations due to loss of bearing capacity arise that cause the liner surfaces to no longer fulfil the requirement for unidirectional fall towards the leachate collection system; and that
- during execution of the work no wheel tracks produced are greater than the requirements for evenness of the finished surface.

7.4.3 **Liner protection**

Liner protection
The lower side of the liner system should be protected against puncture and tearing by stones in the natural deposits or the backfilling.

The top side of the liner system should be protected throughout by, as a minimum, an 0.3-metre layer of sand/gravel with a uniformity coefficient greater than 3, cf. DS/R 466, which also meets the design criteria in para. 8.5.1 hereof.

Climatic effects
Any drying-out of liner systems that include a clay liner should be prevented by moistening the liner surface and protective layer during dry weather periods - until the liner has been covered by the first layer of waste.

Freezing of bottom and side liner systems containing clay should be prevented by covering with protective gravel and/or waste.

Protective layer
Cf. sect. 7.3 above.

7.5 **Quality Assurance for Liner Systems**

Quality assurance
Quality assurance for liner systems is carried out as a check of the individual components of the overall project. At the start of the design phase a control plan is drawn up; the plan will specify who is responsible for the control as well as the extent of the control at the various stages of the project. The control should include the design itself as well as a control of materials and

execution. The control must be planned, executed and interpreted by technicians with sufficient insight and background. Records should be kept of the checks performed. The records must contain data and evaluations and should be kept as part of the final design documentation.

In addition to control (material and execution control) of all the materials included in the liner system, the liner subgrade and the protective layer should be subjected to control.

In general, the first requirement for the quality of the liner system is the use of highly qualified staff for the design as well as the execution.

8 Leachate Collection

8.1 Definition and Strategy

A leachate collection system is a system designed to remove efficiently and quickly any leachate from the liner surface of a landfill, so that at no time there will be a hydraulic pressure over the liner surface exceeding 30cm. If this is fulfilled, no significant hydraulic pressure will occur on the liner surface. The risk of release of leachate through leaks, if any, in the liner is therefore substantially reduced.

Furthermore, the leachate collection system must guarantee that leachate is discharged for treatment before final discharge to the recipient.

The leachate collection system must be operational throughout the active phase of the landfill. For that reason the leachate collection system must be simple, safe and durable. The system should not include components in inaccessible places that may require repairs. Inaccessible components must be designed so that their useful life covers at least the active phase of the landfill.

Components of the leachate collection system that may require replacement or repair must be easily accessible.

8.2 Components of a Leachate Collection System

A leachate collection system of a landfill is a system of construction elements (components) that collect and remove leachate from the landfill. The main components of a leachate collection system are:

- Collection unit (drainage gravel layer, side drains and, to some extent, the main drain);
- transport unit (main drain and, to some extent, side drains);
- intake system for the collection well (load distribution plate, etc.);
- collection well, inspection wells, sampling well and, as the case may be, pumping well;
- discharge pipe (gravitation and pressure pipes).

Table 8.1

Components of a leachate collection system with specification of the possibilities of maintenance and the requirements that should be made for quality control in connection with design and execution.

CONSTRUCTION COMPONENT	PROSPECTS OF MAINTENANCE	CONTROL LEVEL	
		Design	**Execution**
Drainage:			
Drainage gravel layer	Unfeasible	Normal	Stringent
Side drains	Unfeasible	Normal	Stringent
Main drains	Partly feasible, through collection well	Stringent	Stringent
Inspection well	Unfeasible	Normal	Normal
Intake system	Unfeasible	Normal	Stringent
Collection well	Partly feasible. Readily accessible inside	Normal	Normal
Discharge pipe	Feasible	Normal	Normal

8.3 General Design Criteria

The main concept behind the design of the leachate collection system is:

- a simple, safe and durable design; and
- to avoid any use of inaccessible components that may fail.

Generally speaking, the following rules should be observed:

- The design of the drainage system must be chosen on the assumption that the variations of the leachate in terms of quantity, chemistry and biology *cannot* be regulated.
- The flow rate in the selected components must be kept as low as possible and without sudden variations in places without realistic prospects of repair.
- Only justified flow-disturbing components such as drain pipes and wells should be used. Geotextiles should be avoided.
- Components that require maintenance or have a useful life which cannot meet the demands for active environmental protection systems should be used only as an exception and then only as strictly necessary.
- In connection with any choice of functions it should be considered if the functions could be carried out in a simpler manner and with more resistant materials. If so, it should be considered to change the design.

8.4 Design Intensity

The design basis for the hydraulic capacity of a drainage system must be determined on the basis of, among others:

- The precipitation pattern at the relevant site.
- Recirculation and/or watering.

Where no recirculation/watering is carried out at a landfill, a leachate collection

system should be dimensioned to a capacity corresponding to the actual precipitation. As a starting point, *the maximum monthly precipitation for an average year (data from the most recent 30 years) for the relevant site* should be used. This capacity will be necessary until the liner surface of the landfill is covered by at least one layer of waste.

Where recirculation/watering is planned for the landfill, this must be included in the design intensity. Please refer to DS/R 466.

8.5 **Design of Individual Components**

All components incorporated into the leachate collection system should be dimensioned with a safety factor of at least 2. This implies that the leachate collection system must be capable of draining the design intensity if the capacity of the drainage system is reduced by half due to clogging.

8.5.1 **Drainage and protective layer**

The hydraulic pressure level of the leachate over the liner surface may nowhere exceed the thickness of the drainage and protective layers. In the design, the hydraulic pressure should be set as not more than 30cm.

The permeability and grain size of the drainage layer should be adapted to the nature of the leachate likely to be generated from the waste - so that efficient drainage is ensured and no clogging of the drainage layer occurs.

Otherwise, any design of the drainage and protective layer should adhere to the rules in DS/R 466.

8.5.2 **Side drains**

A network of side drains with drainage direction towards the main drain should be installed in the drainage gravel layer, cf. para. 8.5.3.

The design of side drains should be based on the instructions in DS/R 466.

Choice of materials
Side drains should be built as stone fascines made of mutually stable filter materials (shingle, pea gravel, perlite, filter gravel, etc.). Geotextiles should not be used as a solution to meet the filter criteria. If, none the less, it is necessary to use geotextiles, the permeability and risk of clogging of the geotextiles should be carefully considered.

Distance between drains
The distance between two side drains should not exceed 0.5 x the theoretical distance and be at a maximum of 20 metres.

Width of the drain
The width of the side drain fascine should be determined as at least 2 x the theoretical width of the fascine based on the necessary capacity.

Length of the drain
The length of the side drain must be adapted to the ”catchment area” of the main drain, cf. para. 8.5.3.

8.5.3 **Main drains**

Main drains should be placed in the drainage gravel at the lower level of the liner surface with direct drainage towards the intake system and collection well.The dimension of the main drain is determined by the design intensity and on the basis of the catchment area of the main drain (the liner surface with run-off to the main drain). If a drainage pipe is installed in connection with the stone fascine, its capacity should not be taken into consideration.

The design of main drains should otherwise be based on the instructions in DS/R 466.

Choice of materials
Main drains should be built as stone fascines made of mutually stable filter materials (shingle, pea gravel, perlite, filter gravel, or similar) with the addition, as the case may be, of drainage pipes of polyethylene, etc. Geotextiles must not be used as a solution to meet the filter criteria.

Distance between drains
The distance between main drains should be adapted to the capacity of the main drains and their catchment area.

Width of the drain
The width of the main drain fascine should be determined as at least 2 x the theoretical width of the fascine fixed on the basis of the necessary capacity.

Catchment area
The catchment area of a main drain should not exceed what corresponds to a damming up of 30cm in the main drain at the intake system to the collection well. The catchment area of the main drain can therefore be calculated as follows:

$$O_H \leq \frac{0{,}3[m] x \frac{b_H}{2} x \ K_H}{I}$$

where:
O_H = Maximum catchment area (m^2) of the main drain.
b_H = Width of the main drain (metres)
K_H = Capacity of the main drain (m/sec.)
I = Leachate design intensity (m/sec.)

Length of the drain
In most cases the length of a main drain should not exceed 75 metres.

8.5.4 **Intake system for collection well**

An intake system for a collection well is intended to ensure that the leachate has direct access to the collection well. This system is of vital importance and must be fully operational throughout the active phase of the landfill.

An intake system should consist of a high-permeable layer of gravel in which drainage pipes have been laid out with intake to the collection well. The intake system should be protected by a load distribution plate installed on top of it.

The dimensions of the intake system must be based on the design intensity, cf. sect. 8.4, and the liner surface having run-off to the collection well.

As a minimum, the dimensioning basis for the intake system should be as follows:

- The intake capacity is determined as at least 2 x the theoretical capacity of the intake system, with not less than two intake strings to the collection well.
- The intake system should be able to resist a load corresponding to at least 2 x the theoretical pressure from the overlying waste and soil.
- The intake system should not receive direct infiltration of leachate generated from overlying waste (to avoid direct precipitation of particles in the intake system).
- As a minimum, the intake system should cover an area around the collection well which corresponds to a distance from the collection well of at least 5 metres.

Choice of materials
The intake system should be built as stone fascines made corresponding to the most permeable material used in the main drain.

The intake strings to the collection well should be made of drainage pipes of materials resistant to leachate.

8.5.5 **Collection wells**

The collection of leachate from a landfill unit should occur via a collection well. Thereby it is possible to draw samples of leachate and to gain access as required to the drainage pipes of the intake system. Leachate is removed from the collection well by pumping or by a gravitation outlet under the liner to a common pumping station for the landfill.

The dimensions of the collection well are determined by the design intensity, cf. sect. 8.4, and the catchment area having run-off to the collection well. The design of the capacity of the collection well and the necessary pumping output is otherwise subject to the general practice for drainage systems.

In order to avoid excessive heights of the collection wells they should be placed where the filling height of waste is lowest. At the same time this provides improved access to the collection well.

A collection well should be able, as a minimum, to resist a load corresponding to at least 2 x the theoretical pressure from waste and soil.

Design
The collection well should be designed in a manner which allows for the design criteria in sect. 8.3, and which makes it possible to draw samples of leachate for analysis from all intakes.

Furthermore, the collection well should be designed in such a manner that most of the activities that are to be carried out in the collection well can be completed without any persons being present in the collection well. If it is expected that there will be a need to send persons down into the collection well, it must be designed so that this can occur only subject to special safety precautions.

To the extent that discharge is made to sewer system and rainwater discharge systems, Statutory Order of the Directorate of National Labour Inspection No. 473 of October 7, 1983, on Sewage Work, etc., shall apply. Where this is not the case, the design requirements in the Statutory Order on Sewage Work etc. shall form the basis for a specific assessment.

Choice of materials
If concrete is used for the construction of collection wells, the concrete must be treated - inside as well as outside - with leachate-resistant coating agents.

Suitable materials for collection wells are, in particular, glass-fibre reinforced polyester (GRP) and - where the height of the collection well is moderate - polyethylene high density (PEH). These materials, too, must be coated on the inside with leachate-resistant coating agents.

8.6 **Control Systems**

To be able to check the effectiveness of the leachate collection system, small vertical monitoring pipes should be installed with hydraulic contact to the drainage gravel layer. The control pipes are placed so that they adequately reflect the leachate level over the liner.

The monitoring pipes can be led through the waste gradually as it is filled. When the pipes are installed, measures should already be in place to prevent puncture of the underlying liner.

Another feasible method to check the effectiveness of the leachate collection system is to assess the collected quantity of leachate in relation to the quantities of precipitation and leakage control in connection with groundwater monitoring.

8.7 **Quality Assurance**

When designing all the components of a leachate collection system, documentation should be prepared, including the choice and durability of the materials. The design basis should be enclosed with the application for environmental permit.

9 Gas Management

9.1 **Definition and Strategy**

With the overall strategy for the landfill of waste contained in the Danish Environmental Protection Agency's Plan of Action for Waste and Recycling - which aims to minimise the volume of waste for landfilling - and Chapter 2 of this Guideline, only small quantities of gas will be generated.

For the individual types of landfill unit, the assessment is as follows:

Landfill unit for inert waste

The very nature of the waste that can be accepted for landfill in such a unit implies that gas will be generated on an insignificant scale only.

Landfill unit for mineral waste

The nature of the waste that can be accepted for landfill in such a unit implies that the generation of gas will be very small.

Landfill unit for mixed wastes

In a unit of this type it is likely that a certain - but still modest - quantity of organic waste and slowly decomposable organic waste will be landfilled. Therefore, in the light of the knowledge of the landfilled waste, an environmental evaluation should be made as to whether the generated gas must/can be collected and, as the case may be, recovered for energy generation.

Bioreactor landfill

In a unit of this type considerable quantities of organic matter will occur; therefore, collection and recovery of the gas should also be undertaken.

Where gas is generated from landfilled waste, the gas must be managed in an environmentally sound manner. During the operating phase the gas must be handled to ensure that no explosion risk will arise, and to reduce the risk of fire in the landfilled waste. Subsequently, the management of gas should aim to eliminate the risk of damage to vegetation in the final cover of the landfill and/or the surroundings.

10 Operation

10.1 Definition and Strategy

The operation of a landfill must at all times follow the guidelines stated in the environmental permit of the facility.

Basically, the operation of each unit of the landfill must be so arranged that the impact on the external environment and the occupational health and safety - notably in the form of emission of dust and noise - is reduced as much as practicable.

The operation of a landfill must be arranged in such a manner that it is adapted to the types of waste received at the landfill.

Because the checking of the waste should in itself be the most important environmental protection measure, the control of the waste received - and the control as to which landfill unit the waste is placed - must be a crucial part of the operation.

Furthermore, the operation of a landfill must always comply with rules and regulations from other authorities, including the Directorate of National Labour Inspection and the Fire Inspection.

This chapter excludes the operation of separation facilities, as this aspect is beyond the scope of this Guideline.

10.2 General Operating Conditions

Many operating conditions will be independent of the number of units in the landfill. The general operating conditions that should be taken into consideration, as a minimum, in connection with every landfill are dealt with in the following paragraphs.

10.2.1 Registration and control of waste

At every landfill the staff at the reception office must, for each load of waste, carry out a registration and control of the waste arriving at the landfill. This will ensure that the waste received and registered corresponds to the permitted type. Furthermore, the operating staff must decide in each individual case in which landfill unit the waste is to be landfilled.

The acceptance criteria for waste at landfills will appear from the environmental permit of the landfill, cf. also the guidelines listed in Chapter 4: ”Waste Acceptance Procedures”, and in Annex A.

Responsibility for the registration rests on the operation manager of the landfill. The legal responsibility for waste accepted at a landfill rests on the owner of the landfill.

Registration

Every load of waste arriving at the landfill must be registered (even loads that are rejected). The registration should comply with the procedure described in sect. 4.5.

Reception control
The staff at the reception office must check that the load of waste qualifies for acceptance according to the procedure described in sect. 4.5.

Assignment of landfill unit
On the basis of the details registered for the waste the staff at the reception office will assign the waste to a specific unit.

Control at the landfill unit
At the tip face the driver will make a visual inspection to ensure that the waste is of the permitted type for the relevant landfill unit.

Rejection procedure
Waste that has to be rejected at the reception office should follow the procedure described in sect. 4.5. Waste that has to be rejected after unloading should be removed, if possible, by the lorry driver who brought the waste. Where this is not possible, an alternative solution must be devised immediately - for example, by loading the waste into an empty container with a view to being taken to the correct treatment later on.

10.2.2 **Placing the first layer of waste**

The first layer of waste should be placed so that the greatest possible consideration is shown for the active environmental protection systems installed.

In practice, this implies that the first layer of waste should be placed with a thickness of about one metre, before any compaction is made. All activities should thus be carried out on top of the layer of waste first placed. The first layer of waste must not contain objects that could puncture any of the active environmental protection systems.

10.2.3 **Traffic**

Traffic within the landfill should be so arranged that it provides the highest degree of traffic safety and the lowest degree of nuisance - especially in the form of dust and noise - for the staff and others who are present in the landfill.

10.2.4 **Cleaning and maintenance**

Cleaning the areas
Paved areas and roads in the landfill should be always be kept clean from waste, dust, soil, snow, etc. This can be done by daily sweeping. When sweeping, dust nuisances must be prevented by sprinkling with clean water.

Fences, etc. must be kept clean from waste.

Cleaning of vehicles leaving the landfill
It is the driver’s responsibility that the vehicle is cleaned before it leaves the landfill, so that it does not give rise to the spreading of waste and dirt on public roads.

Maintaining the equipment
The equipment at the landfill should be maintained as directed by the supplier.

Equipment necessary for the filling of waste, as well as leachate pumps, etc., must be maintained at all times or be capable of prompt replacement.

Maintaining components of the landfill facility
All components of the facility must be maintained. This includes embankments, ditches, collection wells, basins, oil separators, fences, vegetation, internal roads, control wells, etc.

10.2.5 **Size of the tip face**

Each unit of a landfill should have only one tip face. This tip face should be confined to a delimited area of the unit. The size of the tip face will depend on the quantities of waste received; however, there should be space for the unloading of only a limited number of vehicles at the same time. The number of vehicles must not exceed what the operator(s) at the tip face can oversee. In practice, this will correspond to about three simultaneously unloading vehicles for each landfilling vehicle operating on the unit.

10.2.6 **Restoration**

Any landscaping and restoration of a landfill must be performed continuously as the individual landfill units are being filled, cf. para. 5.5.5 and Chapter 12. This aspect of the work should therefore form a natural part of the operation of the landfill.

10.2.7 **Emergency procedures**

In the event that emergencies occur at the landfill, all staff must be familiar with the emergency procedures so that they can remedy the relevant situation as quickly as possible. Emergency procedures may differ from one landfill facility to another. The following procedures should be regarded as guidelines only.

General rules
Responsibility for the emergency procedures rests on the operation manager. The emergency procedures must always be specified in the operating instructions for the landfill.

Fires
Fires breaking out in waste at the landfill should be fought promptly by choking the fire. This should *not* be done with water but by covering the waste with large quantities of soil followed by compaction. Suitable equipment for this is a compactor which is cooled by being sprayed with water.

Groundwater pollution
If unintended release of leachate to the groundwater or surface water is detected, or if this is noted in the groundwater monitoring, the inspeciton authorities must be notified immediately.

Accidents
If an accident occurs at the landfill, the person(s) must be given prompt treatment, and the Directorate of National Labour Inspection shall be notified of the accident.

Equipment breakdown
Breakdowns lasting a full working day or more of equipment used for the filling of waste must lead to the provision of replacement equipment. This procedure

should be described in the operating instructions.

Breakdown of the leachate pump, etc., should be recorded automatically. The pumps should be repaired or replaced as soon as the breakdown is noted.

10.3 **Landfilling Methods**

Each landfill unit will have its own methods that must be used for the placing and filling of waste in the environmentally optimum manner.

The following contains recommendations for guidelines as to the equipment necessary for placing and filling the waste, daily covering, control at the tip face, as well as the management of special types of waste. Operating methods are described for landfill units for mixed wastes, mineral waste, and inert waste. Regarding the ”bioreactor landfill” please refer to Annex C.

10.3.1 **Landfill unit for mixed wastes**

Equipment for filling
Compactors should be used for the filling of mixed wastes, as such waste can be highly inhomogeneous. Mixed wastes should be crushed and homogenised (in practice: mixed) before filling.

Filling
The waste should be filled in thin layers (thickness not more than 30cm) and compacted by being run over repeatedly by a compactor. The first layer should be ”crushed” outside the working area before being placed in layers of about one metre, for which purpose a blade dozer may be used. Only for the subsequent layers should compaction be carried out.

Covering
The purpose of the daily covering is to prevent any escape of waste and to reduce the risk of odour and vermins.

If the waste is intensively compacted in accordance with the above, the daily covering can in most cases be dispensed with or reduced to a minimum.

Where daily covering becomes necessary, it should be laid out in layers that are no thicker than necessary to obtain the desired effect.

Material used for daily covering must be permeable so as to ensure that the precipitation is evenly distributed in the waste and, thereby, ensure that the leaching from the waste is comparatively even. Dust may be suppressed by sprinkling the waste with clean water.

Control at the tip face
The waste should be unloaded at the top of the tip face. This enables the driver to assess the composition of the waste upon unloading. During filling it is also possible for the driver to observe any unwanted fractions in the mixed load of waste. Unwanted fractions of waste should be removed.

10.3.2 **Landfill unit for mineral waste**

Equipment for filling
Blade dozers or wheel loaders may be used for the filling of inorganic waste if it consists of fractions that require no crushing. If the waste does require

crushing, a compactor may be necessary. To achieve satisfactory filling of mineral waste a roller may be used.

Filling
Waste should be filled in layers with a thickness of not more than 30cm. To minimise subsequent settlement of the waste the filling should be carried out by running repeatedly over the waste with a roller or other heavy equipment. The first layer of waste should be placed in layers of about one metre.

Covering
Daily covering is not considered necessary for the types of waste likely to arrive in this type of unit. Dust may be suppressed by sprinkling the waste with clean water.

Control at the tip face
Waste should be unloaded at the top of the tip face. This enables the driver to assess the composition of the waste upon unloading. During filling it is also possible for the driver to observe any unwanted fractions in the waste. Unwanted fractions should be removed.

10.3.3 **Landfill unit for inert waste**

Equipment for filling
Compactors and/or blade dozers should be used for the filling of inert waste. The decision must be based on the composition of the waste. A compactor should be used if the waste requires crushing and homogenisation (in practice: mixing) before filling.

Filling
The waste should be filled in layers with a thickness of not more than 30cm. The filling should be carried out by repeatedly running over the waste.

Covering
Daily covering is not considered necessary for the types of waste likely to arrive in this type of unit. Dust may be suppressed by sprinkling the waste with clean water.

Control at the tip face
The waste should be unloaded at the top of the tip face. This enables the driver to assess the composition of the waste upon unloading. During filling it is also possible for the driver to observe any unwanted fractions in a mixed load of waste. Unwanted fractions should be removed.

10.3.4 **Bioreactor landfill**

A bioreactor landfill must be established where there may still be a need to landfill domestic waste and other waste with a high organic content. Annex C contains a more detailed description of a bioreactor landfill.

10.4 **Operating Instructions**

For every landfill there must be operating instructions. The purpose of the operating instructions is to clarify responsibility and competence in connection with the management of the landfill. Also, the operating instructions must lay

down guidelines for the work routines applying to the landfill so that the operation can meet the requirements specified in the environmental permit for the landfill.

As a minimum, the operating instructions should contain the following parts:

- Ownership;
- important addresses and telephone numbers;
- holders of the operating instructions who are always in possession of the most recent version;
- description of the layout with its breakdown into landfill units and the levels of active and passive environmental protection systems;
- the machinery of the landfill;
- waste acceptance criteria;
- procedures for waste rejection;
- an operating description of each activity for which the landfill has been approved. The operating description should include at least:
    - The landfilling activities, including the thickness of layers when filling, and - where daily covering is deemed necessary - materials likely to be used for that.
    - The treatment activities, including how and which equipment is to be used.
    - Emergency procedures, such as in connection with fires, industrial accidents, machinery breakdowns, etc.
    - Mitigation procedures for nuisances such as dust, odour, vermins, etc.

- Maintenance regulations for each layout component of the landfill, including the maintenance of sewer systems for leachate, wastewater and surface water;
- control procedures pursuant to the control conditions specified in the environmental permit;
- standards for the drawing of samples in connection with the control procedures; and
- a listing of standards for the reporting of control procedures to ensure that the reporting is uniform every year.

The operating instructions should be arranged in such a manner that they can be revised continuously as and when there are changes at the landfill. Each page of the operating instructions should therefore be laid out so that it is always possible to see the date of the most recent revision of each page. Furthermore, the table of contents should always contain the newest revisions with the dates of the most recently revised pages.

Because, pursuant to Statutory Order of the Ministry of Labour No. 1182 of December 18, 1992, on the Execution of the Work, it is up to the employer to make sure that employees receive proper instructions, occupational health and safety can appropriately be incorporated into the operating instructions.

10.5 **Guidance for Customers**

For the information of suppliers of waste to the landfill, signboards should be erected outside the landfill with details of ownership, operating hours, the units available at the landfill, and to whom the facility is open.

The landfill should also draw up a manual for suppliers of waste specifying the acceptance criteria applying to the reception of waste, as well as the rejection procedures that are in force.

11 Control and Inspection

11.1 Definition and Strategy

Control and inspection of a landfill must be carried out to make sure that the purpose of the active and passive environmental protection systems is being observed, and that the operation of the landfill is carried out in an environmentally sound manner and in accordance with the operating instructions.

Control
In this sense ”control of a landfill” means the self-control exercised at the instance of the owner of the landfill.

This self-control must be the most important factor in safeguarding against the impact of the landfill on the surroundings. To achieve this, the self-control must include an assessment of the parameters for which checks are carried out. The extent of the self-control is laid down in the environmental permit of the landfill and should normally include at least checks of the following:

- Active and passive environmental protection measures (liners, drainage systems, leachate pumps, sewer systems, etc.);
- acceptance of waste at the landfill;
- leachate, groundwater and surface water, including methods of analysis and detection limits;
- noise; and
- other impacts (odour, dust, vermins, etc.).

The results of the self-control are reported routinely once every year. In addition to the results, this annual report must also include an evaluation of the results.

Inspection
Inspections of the landfill are carried out by the inspection authority. The inspection authority makes a number of unannounced visits each year. These visits and the annual reports with the results of the self-control must enable an ongoing revision of the control programmes for the landfill.

If the operation or the self-control reveals irregularities that might have an impact on the environment, the inspection authority *must* be notified promptly.

11.2 Construction Activities

The purpose of controlling the construction of a landfill is to ensure that the construction work proceeds in accordance with the approved specifications for the work. There is thus a quality control of the work performed.

The quality control should include, first and foremost, the active environmental protection systems, the liner systems, cf. Chapter 7, and the leachate collection systems, cf. Chapter 8.

In most cases the quality control is carried out by the contractor and the developer’s supervision.

The control can include samplings and analysis of the materials used. In most cases it will be a matter of geotechnical sampling of the materials used - such as sand, gravel and clay. It may also include control of the filling of various materials, including parameters for permeability of the clay materials used, in the form of compression control. Regarding control of liners please refer to sect. 7.4 and the instructions in DS/R 466.

Regarding leachate collection systems please refer to sect. 8.7 and the general procedures for quality control contained in DS/R 466.

11.3 **Waste**

Every load of waste received at a landfill must be registered and accepted in accordance with the guidelines specified in sect. 4.4.

These guidelines represent the actual control of waste received for landfilling. In addition, a visual inspection of the unloaded waste is made at the tip face. This inspection is a subjective one, cf. sect. 10.2, and is not registered.

11.4 **Leachate**

The purpose of monitoring the leachate is to describe the composition and degree of pollution of the leachate. The results of the monitoring must be capable of being used:

- to optimise the control of groundwater and surface water, including the choice of suitable indicator parameters;
- as the basis for 1) the choice of leachate treatment and 2) the control of the composition of leachate in relation to a given treatment in, for example, a wastewater treatment plant;
- as decision basis in determining when the active systems of the landfill can become passive ones.

Samples
Samples of leachate are drawn from the collection wells at the landfill. If the landfill is subdivided into several units, samples should be drawn from each of these.

Recording of quantity
The quantity of leachate should be recorded. Measurements should be stated, as a minimum, on a weekly basis.

For the purpose of checking the quantities of leachate, a daily recording of meteorological data should also be made, among them:

- Precipitation;
- temperature; and
- wind speed and direction.

Analysis parameters

Based on the knowledge of the nature of the waste landfilled and the purpose of the leachate control, two analysis programmes are established: a routine programme and an extended programme. Table 11.1 shows a list of parameters that may be used as a starting point for the choice of analysis parameters for leachate control.

Table 11.1

Analysis parameters, leachate control.

PARAMETERS	LANDFILL UNIT					
	INERT WASTE*		MINERALS WASTE		MIXED WASTES	
	Extended	Routine	Extended	Routine	Extended	Routine
pH	D	D	D	D	D	D
Conductivity	D, K	D, K	D, K	D, K	D, K	D, K
Dry matter	D	D	D, R	D, R	D, R	D, R
BI_5					D, R	
NVOC	D, K		D, K, R		D, K, R	D, K, R
AOX			D, K, R		D, K, R	D, K, R
GC-FID-screening					D, K	
Total-N	D		D, R		D, R	
Ammonium-N					R, K	R, K
Chloride	D, K	D, K	D, K, R	D, K, R	D, K, R	D, K, R
Sulphate	D, K		D, K	D, K	D, K	D, K
Sulphide	D		D, R	D, R	D, R	D, R
Sodium	D, K		D, K		D, K	
Calcium	D, K		D, K		D, K	
Iron			D, R		D, R	
Potassium			D, K, R			
Lead			D, R		D, R	
Cadmium			D, R		D, R	
Copper			D, R		D, R	
Chromium (total)			D, R		D, R	
Nickel			D, R		D, R	
Zinc			D, R		D, R	

D = Parameter related to the general pollution state of the landfill unit
K = Parameter related to the control of groundwater and surface water
R = Parameter related to the treatment of leachate
NVOC = Non-Volatile Organic Carbon
AOX = Adsorbable Organically Bound Halogen
GC-FID screening = Screening by gas chromatography for contents of extractable, organic substances, including solvents and oil products
* = Where the composition of the leachate can be checked, cf. sect. 3.2.

Extent

The list of parameters for a given landfill should not necessarily include all the parameters listed in Table 11.1. Also, in the case of certain landfill units, it may be necessary to choose parameters that are not listed in Table 11.1.

Analysis laboratory
Analyses must be performed by an analysis laboratory accredited to carry out the relevant analysis. Any use of non-accredited laboratories requires acceptance from the inspection authority.

Adjustment of analysis programmes
It is important that the need for adjustment of relevant analysis programmes is evaluated on an ongoing basis. Specifically, it is reasonable to assume that there may be a need for adjustment of the routine analysis programme. The extent of this programme should be considered critically every time results are available from the extended analysis programme.

Frequency of analysis
Table 11.2 contains a proposal for recommended intervals between the carrying-out of control under the extended programme and the routine programme, respectively. The proposal includes intervals for the period during the filling of the landfill and the period after the landfill has been filled, and until the active systems become passive ones. After that, no control of leachate has to be performed, cf. sect. 12.7.

Table 11.2
Frequency of analysis for leachate control

MONTH	LANDFILL UNIT			
	DURING FILLING		AFTER FILLING	
	Extended	Routine	Extended	Routine
1		X		
2				
3				
4		X		X
5				
6				
7		X		
8				
9				
10	X			X
11				
12				
1		X		
2				
3				
4		X		X
5				
6				
7		X		
8				
9				
10	X		X	
11				
12				

11.5 **Groundwater**

The purpose of groundwater control around a landfill is to check if the requirements for the layout and operation of the landfill are being observed, i.e., the groundwater is not being polluted by leachate from the landfill.

Sampling
Groundwater samples are drawn from the monitoring wells, cf. sect. 5.4, which also describes the procedure for the sampling. Before sampling, the wells should be sounded.

Analysis programmes
Analysis parameters for groundwater control at a landfill should be selected, basically, in the light of the composition and degree of pollution of the leachate at the relevant landfill, as well as the groundwater quality in the area. On the basis of the results of these analyses and the expected composition of the leachate, cf. Chapter 3, an analysis programme is drawn up for the subsequent groundwater control. When selecting analysis parameters it is important to consider the mobility of the substances in the groundwater zone.

For landfill units for mixed wastes, mineral waste and inert waste, Table 11.3 contains proposals for such analysis parameters. If one landfill contains several landfill units, the analysis programme should reflect the sum of the parameters for each unit.

Table 11.3
Analysis parameters, groundwater

PARA-METER	**LANDFILL UNIT**		
	INERT WASTE	**MINERAL WASTE**	**MIXED WASTES**
pH	X	X	X
Conductivity	X	X	X
NVOC	X	X	X
AOX			X
GC-FID screening			X
Ammonium-N			X
Chloride	X	X	X
Sulphate	X	X	X
Sodium		X	X
Calcium		X	X

NVOC = Non-Volatile Organic Carbon.
AOX = Adsorbable Organically Bound Halogen .
OC-FIC screening = Screening by gas chromatography for contents of extractable, organic substances, including solvents and oil products

Extent
Analysis parameters for groundwater should not include parameters which are not covered by the choice of parameters for leachate control.

Analysis laboratory
Analyses must be performed by accredited analysis laboratories. Any use of non-accredited laboratories requires acceptance from the inspection authority.

Adjustment of analysis programmes
The need for adjustment of the analysis programme for groundwater control should be evaluated on an ongoing basis in the light of the results of the leachate control. For example, in the event of significant changes in the composition and degree of pollution of the leachate, there might be a need for adjustment of the analysis programme.

Frequency of analysis
After commissioning of the landfill the fundamental basis for determining the analysis frequency is that any pollution from leachate must not be able to move so far during the interval between two samplings that measures cannot be taken to stop the pollution.
This means that the frequency of analysis becomes dependent on the flow rate of the groundwater and, for each landfill, must be determined on the basis of an estimate thereof, cf. Chapter 5.2. The minimum frequency is one groundwater check per year during the active phase of the landfill.

11.6 **Surface Water**

It is only in exceptional cases that it is deemed appropriate to carry out control in surface waters.

Because the purpose is to make sure that the requirements for the layout and operation of the landfill are being observed - i.e., surface waters are not being polluted by leachate from the landfill - the check will be carried out by inspection of the aquifer which is in direct hydraulic connection with the surface water. The control will thus be made in accordance with the programme described in sect. 11.5.

In those cases where control of surface waters is deemed appropriate, the analysis parameters must be chosen on the basis of the relevant recipient as well as the composition and degree of pollution of the leachate at the relevant landfill.

In most cases the traditional monitoring parameters cannot be used, and it may be appropriate to use organisms in which toxic substances and trace elements are accumulated.

11.7 **Post Closure**

After landfilling operations have ceased and up to the time when the active systems are made passive, the control of leachate, groundwater and, as the case may be, surface waters must be carried out according to the guidelines outlined in sections 11.4 to 11.6.

After the active systems have been made passive, it is not deemed necessary to check the leachate. But groundwater and, as the case may be, surface water

control must continue. This should continue at the same analysis frequency as when the landfill was in the active phase.

For each landfill facility the length of the control period will then depend on the conditions within and around the landfill, including especially the flow rate of the local groundwater.

It is recommended that, as a minimum, the control should be continued for two control periods after the active systems have been made passive.

11.8 Criteria for Making the Active Systems Passive

The criteria determining when and how a landfill can pass from active environmental protection systems to passive environmental protection systems should be laid down already during the environmental evaluation of the landfill.

The criteria for the decision to transit to passive environmental protection systems must be based, as a minimum, on knowledge of:

- the composition and properties of the landfilled waste;
- the development in the composition and degree of pollution of the leachate;
- the groundwater conditions and groundwater flow dynamics around the landfill;
- the sensitivity of the primary surface water recipient (which is assumed to be marine); and
- the degree of impact on the surroundings.

The criteria must be based on the acceptability of the spreading and dilution. At the same time it will be a condition that the groundwater between the landfill and the surface water recipient is of limited interest as drinking water. Therefore, the starting point for the assessment as to when it is possible to allow a landfill to pass from active environmental protection systems to passive environmental protection systems can be the impact that will be acceptable in the surface water recipient.

The assessment of the impact from the landfill must be made on the basis of the concentration of substance in the leachate as well as the total leachate flux out of the landfill (i.e., the total quantity of substance leaving the landfill with the leachate).

Overall, it is necessary to apply some simple dilution factors which are based on the hydrogeological conditions in the percolation area and the exchange of water and accumulation conditions in the surface water recipient. Where there is insufficient knowledge of the retention and decomposition mechanisms of individual substances in the groundwater zone, a conservative view should be adopted. This implies that the substances are deemed to have the same flow rate (as the groundwater) and dilution in the aquifer in which the leachate is assumed to be fully mixed before it reaches the recipient.

Before it is finally decided to allow a landfill to pass from active environmental protection systems to passive environmental protection systems, the concentration levels in the leachate must have been stable and at the same

level, or less than the calculated accepted concentrations, for a period of not less than two years.

11.9 **Noise**

Noise emitted from a landfill stems partly from the equipment on the facility and partly from vehicles coming and going, and the unloading from these vehicles. This means that for considerable periods of time the noise level will be fairly constant - unless there are significant operational changes such as replacement of machinery, delivery of increasing quantities of waste, changed operating hours, commissioning of new landfill units, installation of noise barriers, etc.

On the other hand, noise levels will vary considerably and randomly over a shorter period of time due to the variation of the delivery of waste within the daily operating hours.

It will therefore be appropriate to carry out noise emission measurements on all significant noise sources and then make a calculation of the noise impact at the most noise-affected spots. Control of the noise impact is made by means of emission measurements with subsequent calculation of the noise impact.

Alternatively, measurements of immissions may be made. Immission measurements made on a single day will be subject to some uncertainty, as the measurements reflect the noise pattern only for the operating conditions during the period of measurement. To determine the noise impact it can therefore become necessary to carry out several measurements.

Emission measurements
The determination of the noise emission and the calculation of the noise impact should be made in accordance with the Danish Environmental Protection Agency's Guideline No. 5/1993: "Calculation of external noise from enterprises".

Immission measurements
These measurements should be made in accordance with the Danish Environmental Protection Agency's Guideline No. 6/1984: "Measurement of external noise from enterprises".

Frequency of control
The extent of the noise control depends on the impact of the landfill on the surroundings. The impact is a function of the activity on the site as well as of the distance to noise-sensitive built-up areas, etc.

The first noise control should be made about six months after commissioning of the landfill - when operations are thought to proceed typically. The control may be carried out either as emission measurements with subsequent calculation or as immission measurements.

Subsequent measurements/calculations are determined on the basis of local conditions and the above observations as to need. Only exceptionally will there be a need for annually recurring measurements.

In the case of very noise-generating landfills a control should be carried out regularly to make sure that the resulting noise level is still acceptable. In the case of landfills with little impact, controls are carried out only if there are significant changes that may serve to increase the noise level.

11.10 **Annual Reporting**

The annual reporting aims to combine the relevant controls carried out at the landfill during the past year. Annual reporting should be regarded as the annual review and assessment of the conditions at the landfill that may have an impact on the environment. The annual report should be addressed to the inspection authority.

As a minimum, the annual report should contain the results of controls of:

- Quantities of waste delivered, broken down by landfill unit (as registered in the ISAG), as well as any leaching tests in accordance with the acceptance criteria, cf. Chapter 4;
- the filling rate and anticipated operational life;
- the quality and quantity of leachate for each landfill unit, cf. sect. 11.4. There should also be a statement of the quantity of recirculated leachate, and the final disposal of leachate;
- groundwater control, where performed, cf. sect. 11.5;
- surface water recipient control, where performed, cf. sect. 11.6;
- noise measurements or calculations according to sect. 11.9; and
- emergencies that have occurred and where emergency procedures have been applied.

All controls performed should be commented on in the annual report and assessed in relation to the environmental permit granted for the landfill and the impact on the external environment. The annual report should also specify remedial action, if any, that has been taken or is likely to be taken.

The annual reporting should be in the form of standard reporting following the same procedure every year. This is especially the case for the quality and quantity of leachate, as well as the quality of groundwater and surface water. The results should be reported in standard schematic form with graphic illustrations.

Construction works should be reported separately in connection with their completion.

11.11 **Inspection by the Authorities**

The inspection authority should pay regular unannounced visits to the landfill. As a minimum, these visits should include inspection of:

- the operation being in accordance with the environmental permit applying to the landfill;
- the state of the environmental protection systems that are accessible;
- the waste received being landfilled in the proper landfill units; and

- the self-control being carried out in accordance with the applicable environmental permit.

At the end of each inspection visit the inspection authority should draw up an inspection record commenting on all the affected circumstances.

In addition, the inspection authority should carry out inspections of the establishment of the landfill and make sure that it is in compliance with the guidelines laid down in the environmental permit. Before commissioning a landfill or parts thereof the inspection authority should grant a commissioning permit.

12 Restoration

12.1 Definition and Strategy

A landfill must be given aftercare so that the objectives for the future use of the land can be fulfilled. The restoration of a landfill must be so designed that the future site appears as an aesthetic entity.

The final covering must be carried out continuously so that each cell of a landfill unit receives its final cover as and when the cell reaches the contemplated profile.

The restoration must be seen in the light of the wish to allow the landfill to pass from the active to the passive phase as soon as possible.

A tight final cover is therefore unacceptable on landfills that require active environmental protection systems. In the long term, impermeable liners cannot be regarded as completely tight. That would imply a risk of putting off a potential pollution to the time when the active environmental protection systems have become passive.

12.2 Physical Design

The physical profile of the future landscape for a landfill should be determined before the landfill is established. The design is limited by a number of factors that must be taken into consideration. The most important ones are dealt with below.

Future landscape
The starting point for the landscape of the restored landfill is the future use of the land.

Regardless of the future use the restored landfill must appear as an aesthetic entity. It should therefore have an appearance which is adapted to the landscape in the region. To achieve this, the design should be made by a person with knowledge of landscaping - such as a landscape architect.

Agricultural use
If the area is subsequently to be used for agricultural purposes with frequent machine tillage, the surface gradients should not exceed about 1:10.

Erosion
To avoid erosion in surfaces with final cover, the surface gradients should nowhere exceed 1:3.

Drainage
The natural run-off of water must be safeguarded in such a manner that no areas will occur within the landfill area with increased influx of surface water

and an associated increase in the production of leachate.

Filling heights
Generally speaking, the filling heights should be as great as possible so that optimum use is made of the liner-covered areas. There should be no areas where the filling height is less than 5 to 7 metres. However, where active environmental protection systems are to be installed on the landfill, allowance must be made for the leaching behaviour of the waste. Thus, the maximum filling height in such places should be determined on the assumption that the active environmental protection systems can be made passive not more than 30 years after the landfilling has ceased, cf. Chapters 2, 4, and 11.

Finally, filling heights around leachate and inspection wells should not be excessive, as this may curb the realistic prospects of maintaining and inspecting the collection wells and/or their installations.

12.3 **Final Covering**

The shape of the final cover depends, firstly, on the landfill unit receiving the final cover and, secondly, on the future use of the land.

12.3.1 **General remarks**

Final covering rate
Under normal circumstances the final covering of the individual landfill units should proceed in keeping with the filling of waste.

Effect on the generation of leachate should be
However, the effect of the final cover on the generation considered carefully in relation to the leaching behaviour of the waste in each landfill unit. Thus, allowance must be made for the fact that not later than 30 years after the end of landfilling the leachate from the relevant landfill unit must be acceptable in the groundwater of the area.

Final cover
The layer of soil used for final covering will have an impact on the storage of water in the final cover - resulting in a reduction of infiltration to the waste. The type and thickness of the layers of soil must therefore be chosen in accordance with the desired effect.

Planting
Generally speaking, the final cover should be seeded or planted just after final covering has been done. There may, however, be circumstances in certain landfill units that would render this inappropriate. The effect of the vegetation must therefore be assessed.

12.3.2 **Cultivation purposes**

In the case of areas that are to be used for cultivation, the guidelines of the Ministry of Agriculture for aftercare of areas for cultivation must be followed.

Cultivation layer
The cultivation layer should consist of an upper cambium of about 0.2 metres

of topsoil and a lower cambium containing clay and silt, so that dessication is prevented and roots can develop.

The soil should be spread so as to avoid compression through traffic. If compression does occur, the soil should be loosened by grubbing.

Cultivation layers without root barriers are established with a total layer thickness of at least 1.7 metres. This will prevent contact between the roots of the crop and the waste.

Root barriers
If a root barrier is installed in the form of, e.g., an 0.15-metre layer of gravel, the thickness of the cultivation layer can be reduced to 1.0 metre. The root barrier should be laid out on a trimmed covering layer.

12.3.3 **Other purposes**

If the future area is to be used for purposes other than cultivation, the primary object of the final covering is to prevent freezing of the waste and to ensure that the contemplated future use of the land is possible. In this case the thickness of the final cover should be at least one metre.

In connection with certain future uses of the land any free infiltration to the waste will be prevented.

In these cases it is necessary to make a concrete estimate of the effect on the leaching behaviour of the waste - so as to make sure that the active environmental protection systems can be made passive not more than 30 years after the landfilling ceased.

ANNEX A

MULTI-LEVEL TEST PROGRAMME FOR THE ASSESSMENT OF WASTE FOR LANDFILLS

Annex A

Multi-level Test Programme for the Assessment of Waste for Landfills

This Annex contains a review of the methods necessary for the testing of a given type of waste at levels 1, 2 or 3 in relation to the acceptance criteria for waste categories I-III as listed in sect. 4.3 of these Guidelines.

Reference is otherwise made to the Danish Environmental Protection Agency's working report "Characterisation of Waste", which is due to be published in 1997.

A.1 Sampling

If a test of the waste implies the drawing of a sample, the same procedure is to be followed - regardless of the level at which the test is being performed.

Until a proper standard method for the drawing of samples of solid waste is available within the framework of CEN, the following provisional procedures should be followed.

Homogeneous waste

"Homogeneous waste" means solid waste the composition of which is uniform throughout the waste matrix as determined by visual inspection.

Samples of homogeneous waste are taken by drawing four times the quantity of waste necessary to complete the test (subject, however, to a minimum of 1 kg). This sample is drawn and shredded in accordance with the principles in ISO 8213-1986 (E).

Heterogeneous waste

"Heterogeneous waste" means all waste that cannot be characterised as homogeneous.

Samples of heterogeneous waste are taken by drawing a representative sample - wherever this is practicable. Parts of the sample that are too large to test and whose identity and properties are known are separated (but are weighed and included in the description of the sample). The rest of the sample is shredded.

Twelve times the quantity of waste necessary to complete the test are drawn (subject, however, to a minimum of 3 kg). Otherwise the sampling procedure is carried out in accordance with the principles in ISO 8213-1986 (E).

A.2 Test programme

For each of waste categories I-III the test programme consists of three test levels. The choice of the necessary level depends on the advance knowledge of the type of waste to be assessed.
Below is a listing of the extent of the test levels for categories I-III followed by proposals for the use of test methods.

Standardisation
A large part of the test methods are being standardised within the framework of CEN and NORDTEST, respectively. The test methods proposed in this Annex will therefore be amended when the standardisation is complete.

Category I: Inert waste

Test levels

Depending on the advance knowledge of the type of waste to be landfilled in a landfill unit for inert waste, the following levels should be used:

Test level 1: Characterisation

Acceptance on the positive list
For waste desired to be accepted on the positive list for Category I, a characterisation test of the waste must be carried out. The characterisation test must include all the surveys I.1 - I.7 (cf. the following section on test methods) and be assessed in relation to the requirements applying to Category I waste.

Test level 2: Compliance testing

Periodical documentation
To substantiate that a type of waste corresponds to a type of waste on the positive list for Category I, an acceptance test must be carried out regularly. Acceptance tests include I.1, I.2 and I.6 (cf. the following section on test methods). For waste received regularly from the same source, the interval between tests could be fixed as 12 months.

Test level 3: Identification

Routine investigation
For all loads of waste received at a landfill an identification test must be performed. This test may consist of a visual inspection of the waste. In special cases, random samples may be drawn for testing of I.1 and, as the case may be, I.2 (cf. the following section on test methods).

For levels 1 and 2 the test must be performed before the waste is brought to the landfill. For level 3 the test is carried out at the landfill.

Test methods

For the assessment of inert waste the following tests I.1 - I.7 may be used:

I.1
Ignition loss determination

The content of organic matter is determined as ignition loss at 550^0C for two hours.

Determination of environmentally harmful substances

I.2
The content of environmentally harmful organic substances may be deter-

mined by gas chromatographic screening analyses, see Note [3].

The content of environmentally harmful inorganic substances may be determined as a total analysis.

I.3

Accessibility test

The quantitative content of pollutants in the waste and its identity may be determined by an ”accessibility test” which should reflect the upper limit of leaching of substance through simulation of natural leaching behaviour. This may be done, e.g., by a pH-static leaching of crushed material at pH = 7 and 4, at a high liquid/solids ratio (L/S ratio), for example 2 x L/S = 100-200 litres per kg. The identity and concentration of the pollutants (expressed in mg per kg) are determined by analysis of specific parameters on the leached eluate. (The development of the method is not yet complete).

I.4

Total chemical composition, (95%)

The total chemical composition (95% knowledge) may be determined by a chemical analysis based on the total analyses made under I.2. The extent of the analysis is determined on the basis of knowledge of the nature and origin of the waste.

The chemical state in the short term and the long term (for example, redox potential, acid/base ratio) must be described.

I.5

Leaching behaviour / reference test

The expected leaching behaviour of the waste as a function of time should be determined, in the case of granular waste, on the basis of column tests. These must describe the leaching behaviour of relevant pollutants at an L/S ratio of 0.1 litres per kg - a maximum of L/S 10 litres per kg. The results should form the reference frames for the leaching behaviour of a waste product. Batch extractions may be added as needed.

NORDTEST has drawn up a description of leaching tests (NORDTEST report No. 272).

Alternatively, for waste in the monolithic form, a tank leaching test may be performed. This is a test method which determines the rate at which a given substance passes from the solid phase to the liquid phase.

I.6

Simplified test

With I.5 as reference, a simplified and less time-consuming test must be per-

[3] Total analysis means a chemical analysis to determine the sample’s total content of all significant components (the content of oxygen can be calculated if it is known that the material is available in oxydised form, such as Al_2O_3, NaO, etc.). It should be stressed that chemical analyses based on partial digestion of the waste matrix cannot be used, i.e., for types of waste that contain silicates, AAS or ICP/ICP-MS may be used - for example - on samples that were digested with nitric acid according to DS 259. Such samples must be analysed after total digestion with, e.g., hydrofluoric acid and aqua regia, or they must be analysed by means of non-destructive methods such as X-ray fluorescence or neutron activation. If the silicate matrix is not completely digested, misleading results may be obtained for, i.a., a number of trace elements that may be contained in it. Such figures are useless for mass balances, etc.

formed. For granular waste this test should be the (expected) standardised CEN test, which consists of two serial batch extractions, first at L/S = 0-2 litres per kg (6 hours' contact time) and then at L/S = 2-10 litres per kg (18 hours' contact time) with an extraction medium of artificial rainwater. The result of this test will be two points on a leaching graph, and the results can then be related directly to the reference leaching behaviour found in I.5.

There is not yet any simplified standard method for waste in the monolithic form.

I.7

Ecotoxicological test

For the determination of the ecotoxicological effect of the leachate from a waste product, a duckweed test (or a freshwater gammarus test) may be carried out on the eluate found in I.5 - with the highest concentrations of pollutants.

Category II: Mineral wastes

Test levels

Depending on the advance knowledge of the type of waste to be landfilled in a landfill unit for mineral waste, the following levels should be used:

Test level 1: Characterisation

Acceptance on the positive list

For waste desired to be accepted on the positive list for Category II, a characterisation test of the waste must be carried out. The characterisation test must include all the surveys II.1 - II.7 (cf. the following section on testing methods) and be assessed in relation to the requirements applying to Category II waste.

Test level 2: Compliance testing

Periodical documentation

To substantiate that a type of waste corresponds to a type of waste on the positive list for Category II, an acceptance test must be carried out regularly. Acceptance tests include II.1, II.2 and II.6 (cf. the following section on test methods). For waste received regularly from the same source, the interval between tests could be fixed as 12 months.

Test level 3: Identification

Routine investigation

For all loads of waste received at a landfill an identification test must be performed. This test may consist of a visual inspection of the waste. In special cases, random samples may be drawn for testing of II.1 and, as the case may be, II.2 (cf. the following section on test methods).

For levels 1 and 2 the test must be performed before the waste is brought to the landfill. For level 3 the test is carried out at the landfill.

Test methods

For the assessment of mineral waste the following tests II.1 - II.7 may be used:

II.1

Ignition loss determination

The content of organic matter is determined as ignition loss at 550^0C for two hours.

Determination of environmentally harmful substances

II.2

The content of environmentally harmful organic substances may be determined by gas chromatographic screening analyses.

The content of environmentally harmful inorganic substances may be determined as a total analysis.

II.3

Accessibility test

The quantitative content of pollutants in the waste and its identity may be determined by an ”accessibility test” which should reflect the upper limit of the leaching of substance through simulation of natural leaching behaviour. This may be done, e.g., by a pH-static leaching of crushed material at pH = 7 and 4, at a high liquid/solids ratio (L/S ratio), for example 2 x L/S = 100-200 litres per kg. The identity and concentration of the pollutants (expressed in mg per kg) are determined by analysis of specific parameters on the leached eluate. (The development of the method is not yet complete).

II.4

Total chemical composition, (95%)

The total chemical composition (95% knowledge) may be determined by a chemical analysis based on the total analyses made under II.2. The extent of the analysis is determined on the basis of knowledge of the nature and origin of the waste.

The chemical state in the short term and the long term (for example, redox potential, acid/base ratio) must be described.

II.5

Leaching behaviour / reference test

The expected leaching behaviour of the waste as a function of time should be determined, in the case of granular waste, on the basis of column tests. These must describe the leaching behaviour of relevant pollutants at an L/S ratio of 0.1 litres per kg - a maximum of L/S 10 litres per kg. The results should form the reference frames for the leaching behaviour of a waste product. Batch extractions may be added as needed.

NORDTEST has drawn up a description of leaching tests (NORDTEST report No. 272).

Alternatively, for waste in the monolithic form, a tank leaching test may be performed. This is a test method which determines the rate at which a given substance passes from the solid phase to the liquid phase.

II.6

Simplified test

With II.5 as reference, a simplified and less time-consuming test must be performed. For granular waste this test should be the (expected) standardised CEN test, which consists of two serial batch extractions, first at L/S = 0-2 litres per kg (6 hours' contact time) and then at L/S = 2-10 litres per kg (18 hours' contact time) with an extraction medium of artificial rainwater. The result of this test will be two points on a leaching graph, and the results can then be related directly to the reference leaching behaviour found in II.5.

There is not yet any simplified standard method for waste in the monolithic form.

II.7

Ecotoxicological test

To determine the ecotoxicological effect of the leachate from a waste product on the leachate treatment plant, a sludge inhibitor test and a nitrification inhibitor test should be carried out on the eluate found in II.5 - with the highest concentrations of pollutants.

Category III: Mixed wastes

Test levels

Depending on the advance knowledge of a type of waste to be landfilled in a landfill for mixed wastes, the following levels should be used:

Test level 1: Characterisation

Acceptance on the positive list

For waste desired to be accepted on the positive list for Category III, a characterisation test of the waste must be carried out. The characterisation test must include all the surveys III.1 - III.6 (cf. the following section on test methods) and be assessed in relation to the requirements applying to Category III waste.

Test level 2: Compliance testing

Periodical documentation

To substantiate that a type of waste corresponds to a type of waste on the positive list for Category III, an acceptance test must be carried out regularly. Acceptance tests include III.1 and III.5 (cf. the following section on test methods). For waste received regularly from the same source, the interval between tests could be fixed as 12 months.

Test level 3: Identification

Routine investigation

For all loads of waste received at a landfill an identification test must be performed. In most cases this test will consist only of a visual inspection of the waste.

For levels 1 and 2 the test must be performed before the waste is brought to the landfill. For level 3 the test is carried out at the landfill.

Test methods

For the assessment of the acceptance criteria for mixed wastes the following test methods III.1 - III.6 may be used:

III.1

Organic matter determination

The content of organic matter must be determined, basically, as ignition loss at 550^0C for two hours.

Where it is not possible to draw a representative sample for the determination of ignition loss, the waste should be shredded so that an assessment in terms of volume may be made of the proportion of organic waste as a ratio of the total volume of waste.

Organic matter in the waste should be described, and the biological half-life of the waste should be estimated.

III.2

Accessibility test

The qualitative and quantitative content of pollutants in the waste may be determined by an ”accessibility test” which should reflect the upper limit of the leaching of substance through simulation of natural leaching behaviour. This may be done, e.g., by a pH-static leaching of crushed material at pH = 7 and 4, at a high liquid/solids ratio (L/S ratio), for example 2 x L/S = 100-200 litres per kg. The identity and concentration of the pollutants (expressed in mg per kg) are determined by analysis of specific parameters on the leached eluate. (The development of the method is not yet complete).

Description of the waste

Heterogeneous types of waste from which it is not possible to draw a representative sample on which an accessibility test can be made must be divided into fractions. Thereupon, each fraction must be described with regard to origin, nature, properties and, if possible, chemical composition.

Environmentally harmful substances in each fraction must be identified and, if possible, quantified.

If necessary, an accessibility test must be made on each of the fractions in the waste, whereupon an estimate is made in relation to the proportion that the fractions represent of the total waste matrix for the type of waste.

III.3

Main composition of the fractions

The waste must be divided into fractions the chemical composition of which should be described (95% knowledge). The extent of the description should be determined on the basis of the nature and origin of the waste.

The chemical state of each fraction in the short term and the long term (for example, redox potential, acid/base ratio) should be described.

An assessment should then be made of the waste in relation to the proportion that the fractions represent of the total waste matrix for the type of waste.

III.4

Leaching behaviour / reference test

The expected leaching behaviour of the waste as a function of time should be determined, in the case of granular waste, on the basis of column tests describing the leaching behaviour of relevant pollutants at an L/S ratio of 0.1 litres per kg - a maximum of L/S 10 litres per kg. The results should form the reference frames for the leaching behaviour of a waste product. Batch extractions may be added as needed.

NORDTEST has drawn up a description (NORDTEST report No. 272).

Alternatively, for waste in the monolithic form, a tank leaching test may be performed. This is a test method which determines the rate at which a given substance passes from the solid phase to the liquid phase.

III.5

Simplified test

With III.4 as reference, a simplified and less time-consuming test must be performed. For granular waste this test should be the (expected) standardised CEN test, which consists of two serial batch extractions, first at L/S = 0-2 litres per kg (6 hours' contact time) and then at L/S = 2-10 litres per kg (18 hours' contact time) with an extraction medium of artificial rainwater. The result of this test will be two points on a leaching graph, and the results can then be related directly to the reference leaching behaviour found in III.4.

There is as yet no simplified standard method for waste in the monolithic form.

III.6

Ecotoxicological test

To determine the ecotoxicological effect of the leachate from a waste product on the leachate treatment plant, a sludge inhibitor test and a nitrification inhibitor test should be carried out on the eluate found in III.4 - with the highest concentrations of pollutants.

ANNEX B

QUALITY REQUIREMENTS FOR BENTONITE LINERS

Annex B

Quality Requirements for Bentonite Liners

This Annex will apply only until the newest revised edition of DS/R 466 is to hand - with specific criteria for bentonite liners.

B.1 Requirements for Materials

Table B.1

Requirements for bentonite liners

PROPERTY	REQUIREMENT
Appearance	No visible faults
Type of bentonite	Montmorillonite > 70%
Quantity of bentonite	Nominal: 4.9 kg/m^2 (not including additives) Minimum: 4.4 kg/m^2 with 15% moisture content and not including additives
Geotextile	The bentonite must be arranged between two geotextiles, one above it and one beneath it. The bentonite material must be attached to the geotextile in such a manner that the bentonite is not placed incorrectly or damaged while it is being laid out and covered. Minimum weight of primary geotextile: 135 g/cm^2
Permeability coefficient	Maximum: 5 x 10^{-11} m/sec at a water pressure of 2 N/cm^2 and a load of 5 kN/m^2
Tensile strength	Minimum: 14 kN/m
Elongation	Minimum: 15% in the direction of the mesh
Puncture resistance	Minimum: 222 N
Joining	It must be possible to carry out joining by simple overlapping of two pieces of liner (minimum 15cm). If loose bentonite is used in the joint, it must be laid out by machine so that uniform sealing is ensured. Joining should be limited as far as practicable.
Additives, glue, etc.	It should be stated if the bentonite liner contains additives and, if so, which. Data sheets should be provided for the relevant additives stating that the additives are resistant to leachate.
References	Documentation should be provided to the effect that the bentonite liner has been successfully installed as bottom liner in a landfill in at least three instances. References must be included, stating the location, the name and address of the owner, the purpose, surface (m^2), and the year.

Before an order is placed the manufacturer of the liner must be able to substantiate that he is capable of delivering a product which meets, as a minimum, the requirements for material specified in Table B.1.

Appearance
When producing the bentonite liner it must be ensured that the liner consists of a uniform layer of bentonite (same thickness of bentonite overall, no holes) laid out between two geotextiles.

Type of bentonite
Bentonite is a soft, rich clay consisting of the clay mineral montmorillonite, which is of volcanic origin. One of the most important properties of bentonite is its ability to adsorb water. The water molecules are bound electrically as dipoles in the diffuse double layer surrounding each clay mineral. The ability to bind water is directly related to the thickness of this double layer and therefore also to the ions that are bound to the surface of the clay mineral. Univalent (+) cations, especially sodium, are not tied quite as strongly to the clay mineral as divalent cations (++); therefore the double layer around the clay mineral will be thicker. The type of ions which are thus bound to the clay mineral (mont-

morillonite) is important to the ability of the bentonite to bind water. Obviously, the quantity of the special clay mineral montmorillonite in the bentonite is also relevant to the ability of the bentonite to bind water.

The ability of European bentonite (high proportion of calcium, Ca) to bind water is thus inferior to that of American (Wyoming) bentonite, which has a high natural content of sodium, Na. The ability of selected types of bentonite to bind water is listed below - expressed as the quantity of water (cm^3) adsorbed per gramme of dry clay:

Wyoming bentonite	:	9-12 cm^3/g
European bentonite	:	2-4 cm^3/g
Treated European bentonite	:	6-9 cm^3/g

As the list shows, European bentonite can be improved by treatment with sodium ions.

Furthermore, the thickness of the double layer in the clay mineral will decrease as the ion strength in the soil/water around the bentonite increases. Therefore, leachate can reduce the thickness of the double layer both through its content of salts and substances that can exchange ions with the original substances (sodium, calcium) in the bentonite.

Quantity of bentonite
Most manufacturers of bentonite liners have a product which contains, nominally, 4.9 kg of bentonite per m^2 (not including additives) and a minimum of 4.4 kg/m^2 at 15% moisture content, not including additives. Besides, most manufacturers can deliver a product which contains precisely the quantity of bentonite needed. The above requirements for materials are thus minimum requirements and reflect the quantity of bentonite which will achieve a permeability coefficient of less than 5×10^{-11} m/sec for the liner.

Geotextile
The bentonite must be arranged between two geotextiles, one above it and one beneath it. In some products the bentonite is fixed to the supporting geotextile by means of a glue; in other products it has been bonded together by needle-punching (a form of sewing) between the two geotextiles. If glue is employed to retain the bentonite, it must be ensured that the glue does not adversely affect the natural properties of the bentonite (the ability to bind water), and that the bentonite is not placed incorrectly or damaged in rolling-up, installation, or covering.

The geotextile which has primary responsibility for retaining the bentonite must have a certain thickness and must be capable of withstanding a certain tension, etc. It is therefore recommended that at least one of the geotextiles in the bentonite liner should have a density of not less than 135 g/cm^2.

Stronger geotextiles may be necessary where the subgrade is very uneven or in the case of steep slopes.

Permeability coefficient
Most bentonite liners have permeability coefficients ranging from 1×10^{-10} to 1×10^{-12} m/sec. The permeability coefficient should be determined

in accordance with DIN 18130 (a water pressure of 20cm and a load of 5 kN/m^2) or ASTM D5084 (2 psi effective load).

Tensile strength
The tensile strength should be at least 14 kN/m^2 determined in accordance with DIN 53857 T2 or ASTM D4632.

Elongation
The elongation must be 15% in the direction of the mesh determined in accordance with DIN 53857 T2 or ASTM D4632.

Puncture resistance
The puncture resistance must be greater than 222 N determined in accordance with DIN 54307 or ASTM D4883.

Joining
It must be possible to carry out joining by simple overlapping of two pieces of liner (minimum 15cm). If loose bentonite is used in the joint, it must be laid out by machine so that a more uniform seal is ensured. The joining method must be stated prior to selection of liner supplier.

References
Documentation should be provided to the effect that the type of bentonite liner has been successfully installed as bottom liner in a landfill area in at least three cases. References must be included, stating the location, the name and address of the owner, the purpose, surface (m^2), and the year.

B.2 Control of Materials

The control of materials must be stringent.

Bentonite liners are supplied in rolls. Rolls that are damaged or show visible defects or are not declared correctly must be rejected by the developer's supervision. The supervision must make sure that the rolls are stored in a dry place and covered by a waterproof tarpaulin.

Strips measuring 30cm x the width of the roll should be taken from a random selection of the rolls delivered in a consignment. Samples are drawn to determine the content of montmorillonite, the quantity of bentonite per cm^2, the permeability coefficient, and the tensile and puncture resistance. The said parameters should be established by a recognised geotechnical laboratory (accredited).

B.3 Control of Execution

The control of execution must be stringent.

Bentonite liners are laid out by machine. An excavator is fitted with a tube and a chain. The tube is placed in the liner roll, and the chain is fixed to the tube. The machine lifts the roll so that the roll hovers 1-1.5 metres above the ground. The machine is driven to the place where the liner is to be laid. Here at least two men will grasp the edge of the roll and put down the loose end of the liner in the

desired place. The machine is driven backwards slowly while the loose end is being held in place. There must be no driving on the liner itself.

In the case of bentonite liners where loose bentonite is used in the joints, the automated equipment for the laying of the loose bentonite must be calibrated separately on a flat subgrade and on slopes. 20 kg of granulated bentonite (+/- 0.5 kg) are spread evenly on 50m of overlapping joint. The equipment must be recalibrated once every week during the installation. In the case of manual laying of bentonite the overlapping joints should be divided into marked sections of 50m each. A 20-kg bag of bentonite must be spread evenly over this stretch. The mode of spreading and the walking speed must be the same throughout the stretch.

On slopes and gradients the liner is also laid by machine, but in such a manner that the machine is stationary at the top while a number of persons pull the liner from the roll. The various liner manufacturers have methods for reinforcement of joints on slopes. Alternatively, it is possible to have pieces of liner produced which are particularly long and which have such a strength that joints on slopes are avoided.

Special care is required in connection with joints around pipe penetrations and similar. Normally, these are made by cutting a hole (a cross with a sharp knife) in the liner where the pipe is to go through. Some loose bentonite may be placed close to the pipe. A piece of liner of suitable dimensions in relation to the pipe, and where the hole for the pipe is precisely cut, is placed on top of the bentonite.

As soon as it has been laid out the liner must be protected by at least 20cm of stabilised gravel. The surface of liner laid out in one day must not be so great that protective gravel cannot also be laid out.

Each manufacturer has prepared installation manuals that are peculiar to the individual products and where the laying and execution of certain pipe penetrations, adhesions to concrete, etc., are described. These installation manuals should always be observed.

B.4 Quality Assurance

Before the bentonite liner is delivered the manufacturer must submit details of quality control data for the rolls which the consignment will include. The desired information must, as a minimum, contain production dates, batch No., roll No., test results, and approval codes. The number of tests, the mean value, standard deviation, minimum average roll value, and maximum average roll value must also be included.

In addition, the contractor must prepare a drawing showing the location of liners and constructional details of the total area to be covered with bentonite liner. The drawing is to be used during the work to indicate the location of each roll No., so that it is known precisely where each individual roll is placed.

At least one control test of overlappings must be carried out on site.

Test of overlappings on site

Equipment

Test box, cover layer material, bentonite.

Procedure

Place a 15cm overlapping in the upper part of the test box.
Seal the edges with bentonite to prevent side leakage.
Place 30cm of cover layer material on top of the overlapping.
Fill the upper box with 45cm of water.
After the initial hydration period (six hours), remove any water that may have seeped into the lower box.
Over a period of seven days - at 24-hour intervals - measure the volume of water in the lower box and record it, indicating the time.

The permeability coefficient (k) for the joint is calculated as follows:

$k = q/A \times i = d/t \times i$, where

q = the flow rate (cm^3/sec.)
A = the area of the test box (cm^2)
i = hydraulic gradient (45 + (2 x 1.25)/(2 x 1.25)) = 19
d = loss of water in cm
t = time from the hydration process was complete (sec.)

The permeability coefficient for the joint must be less than or equal to the permeability coefficient for the liner itself. If the test reveals major deviations - having regard to the uncertainty of the test - the overlapping method must be reconsidered.

ANNEX C

”BIOREACTOR LANDFILL”

Annex C

”Bioreactor landfill”

C.1 Strategy

A ”bioreactor landfill” is a special landfill unit in which waste suitable for incineration may be landfilled under certain conditions.

In regions of Denmark where, due to special circumstances, it is inappropriate or impossible to treat waste suitable for incineration in an incineration plant, the waste may be landfilled in a ”bioreactor landfill”.

The aim is that a ”bioreactor landfill” will optimise the decomposition of landfilled organic waste in a manner that will reduce the organic impact of the leachate and promote the generation of gas as quickly as possible.

Generally, a ”bioreactor landfill” must be designed as any other landfill unit with active environmental protection systems. In addition, the ”bioreactor landfill” must be designed so that it is possible to optimise the extraction of gas from the landfill waste. The extracted gas will be recovered for energy generation.

Admittedly, the overall landfill strategy described in Chapter 2 of this Guideline cannot be fulfilled for a ”bioreactor landfill”.

C.2 Acceptance Criteria for Waste

Waste for landfilling in a ”bioreactor landfill” may be accepted on the basis of the following, restrictive positive list:

- Domestic waste.
- Bulky waste.
- Sewage sludge which has been stabilised in accordance with Statutory Order of the Ministry of the Environment No. 736 of October 26, 1989, and dewatered down to ≥30% dry matter.
- Waste from the positive list for Category III - defined in sect. 4.3 of this Guideline.

In addition, the acceptance criteria for landfill units for mixed wastes, Category III, must be observed.

C.3 Layout

Liner and leachate collection

A ”bioreactor landfill” must be designed with a composite liner system of the type described in Chapter 7 and with a leachate collection system as described in Chapter 8. Furthermore, a ”bioreactor landfill” must be designed so that recirculation of leachate is possible at all times.

Landfill gas management

If possible, there must be access to recover the gas from a ”bioreactor landfill”, and the design must make allowance for that.

Quantities of gas
To determine how the gas is to be managed, a number of estimates should be made of the quantity of gas generated.

Such estimates must be based on experience from other sites where waste of a similar nature is landfilled. The most important elements of such an estimate are the content of organic substances in the waste and the half-life of these substances, as well as the conditions under which it was landfilled in the actual ”bioreactor landfill”, i.e., when anaerobic and methanogene conditions are likely to have been achieved in the landfill unit.

Extraction of gas
Gas may be extracted from the ”bioreactor landfill” *either* by drilling gas wells in the completed landfill unit *or* by installing gas drains continuously during filling. From these the gas may be drawn with a view to being burnt in a combustion chamber.

Explosion risk
When the gas contains 5-15% methane and is in contact with atmospheric air, there is a risk of explosion. The management of gas in a ”bioreactor landfill” must therefore be arranged in a manner so as to prevent gas explosions within the landfill itself - but also to prevent gas from escaping into the surroundings where an explosion risk may arise.

In connection with the design of leachate collection wells it is necessary to take special precautions to prevent gas explosions.

C.4 Operation

Equipment for filling
Compactors should be used for the filling of domestic waste and other mixed wastes, which may be highly inhomogeneous. The waste must be broken open (plastic bags, etc., must be opened) and homogenised (in practice: mixed) with a compactor before being filled. Furthermore, there may be certain types of waste that require shredding prior to filling.

Filling
The waste should be filled in thin layers (not exceeding a thickness of 30cm) and compacted by being run over repeatedly by a compactor.

The first layer should consist entirely of domestic waste. The domestic waste should have been broken open with a compactor away from the tip face and laid out in layers of about 1 metre each.

Covering
The purpose of daily covering is to prevent escape of waste and to reduce the risk of odour and vermins.

If the waste is thoroughly compacted in accordance with the above, daily covering can normally be dispensed with or be reduced to a minimum. The first layer, however, should be covered with permeable soil.

Where daily covering becomes necessary, it should be laid out in layers that are no thicker than necessary to obtain the desired effect.

Material used for daily covering must be permeable so as to ensure that precipitation is evenly distributed in the waste and, thereby, ensure that the leaching behaviour for the waste is comparatively even.

Control at the tip face
The waste should be unloaded at the top of the tip face. This enables the driver to assess the composition of the waste upon unloading. During filling it is also possible for the driver to observe any unwanted fractions in the unloaded waste. Unwanted fractions should be removed for other treatment.

Sludge
Because of its high content of water, sludge may present operating problems. The quantity of sludge landfilled should therefore be confined to a minimum. Sludge should be spread in thin layers and immediately covered with other waste. Where the quantity of sludge becomes excessive, special landfill techniques should be applied.

Road sweepings
During wet periods, and when the content of leaves is high, road sweepings can present problems for driving on the waste. It is therefore recommended that road sweepings should be placed in thin layers and mixed with other waste at the tip face.

C.5 Control and Inspection

The procedures for control and inspection will be as described in Chapter 11 of this Guideline. In connection with the analysis parameters for leachate control, the analysis programme for mixed wastes should be used.

C.6 Restoration

When restoring a ”bioreactor landfill” it must be ensured that infiltration to the waste is adequate to ensure optimum decomposition of the landfilled waste. Also, measures should be taken to prevent damage from gas to the vegetation in the top layer.