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PD CEN/TR 15126:2005

Characterization of sludges — Good practice for landfilling of sludges and sludge treatment residues

ICS 13.030.20

British Standards

National foreword

This Published Document is the official English language version of CEN/TR 15126:2005.

The UK participation in its preparation was entrusted to Technical Committee EH/5, Sludge characteristics, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

The responsible UK committee, EH/5, gives the following advice concerning the contents of CEN/TR 15126:2005.

When European Member State Ministers agreed the EU Landfill Directive they specifically excluded sewage sludge from its reach because they maintained that landfill was needed as a strategic option when no other was available. Member States' implementations of the Directive have not necessarily taken this into account.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the *BSI Catalogue* under the section entitled "International Standards Correspondence Index", or by using the "Search" facility of the *BSI Electronic Catalogue* or of British Standards Online.

Summary of pages

This document comprises a front cover, an inside front cover, the CEN/TR title page, pages 2 to 27 and a back cover.

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TECHNICAL REPORT
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CEN/TR 15126

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English Version

Characterization of sludges - Good practice for landfilling of sludges and sludge treatment residues

Caractérisation des boues - Bonne pratique pour la mise en décharge des boues et des résidus de traitement des boues

Charakterisierung von Schlämmen - Gute fachliche Praxis bei der Deponierung von Schlamm und Rückständen aus der Schlammbehandlung

This Technical Report was approved by CEN on 24 April 2005. It has been drawn up by the Technical Committee CEN/TC 308.

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Contents

Page

Foreword

This document (CEN/TR 15126:2005) has been prepared by Technical Committee CEN/TC 308 “Characterization of sludges”, the secretariat of which is held by AFNOR.

This document is voluntarily presented in the form of a CEN Technical Report because most of its content is not completely in line with practice and regulations in each Member State. This document gives recommendations for good practice concerning the landfilling of sludges and sludge treatment residues, but existing national regulations remain in force.

Introduction

All the recommendations in this document constitute a framework within which the landfilling process can be proposed as a substitute for field spreading, or in addition to specific or combined incinerations, or any other process.

This document should be read in the context of the requirements of Directive 1999/31/EC on the landfill of waste which applies to the landfill of sludge and any other relevant regulations, standards and codes of practice which may prevail locally within Member States.

1 Scope

This CEN Technical Report gives one of a series of sludge management options and describes good practice for the disposal of sludges and sludge treatment residues to landfill where national regulations permit.

This document is applicable to the sludges described in the scope of CEN/TC 308, i.e. specifically derived from:

- storm water handling;
- night soil;
- urban wastewater collecting systems;
- urban wastewater treatment plants;
- treating industrial wastewater similar to urban wastewater (as defined in Directive 91/271/EEC);
- water supply treatment plants;
- water distribution systems;

but excluding hazardous sludges from industry.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1085:1997, *Waste water treatment – Vocabulary*

EN 12832:1999, *Characterisation of sludges – Utilization and disposal of sludges – Vocabulary*

EN 13965-1:2004, *Characterization of waste – Terminology – Part 1: Materials related terms and definitions*

EN 13965-2:2004, *Characterization of waste – Terminology – Part 2: Management related terms and definitions*

CR 13714, *Characterisation of sludges – Sludge management in relation to use or disposal*

3 Terms, definitions and abbreviations

For the purposes of this document, the terms and definitions given in EN 12832:1999, EN 1085:1997, EN 13965-1:2004, EN 13965-2:2004 and also in the following Directives apply:

Directive 91/271/EC concerning urban wastewater treatment

Directive 75/442/EC the waste framework directive as amended by Directive 91/156/EC

Directive 1999/31/EC on the landfill of waste.

Directive 2001/77/EC on renewable energy.

For the understanding of this document, these abbreviated terms apply:

BIO: Biomass
BOD: Biological Oxygen Demand
COD: Chemical Oxygen Demand
CSO: Chemically Stabilized Organic
DPM: Decomposable Plant Material
MSW: Municipal Solid Waste
PSO: Physically Stabilized Organic
RPM: Resistant Plant Material
TOC: Total Organic Carbon
VFA: Volatile Fatty Acids
WWTP:

4 Outline of landfill processes

4.1 General

The landfill processes which are of importance for understanding the potential for controlling waste stabilization are the physical, chemical and microbial activities which lead to the modification of waste, from often complex substances with significant pollution potential to simpler compounds which can be environmentally benign. In the case of a landfill containing degradable waste, the principal processes of interest are those which lead to the breakdown of complex organic compounds found in the putrescible fraction of non-inert waste, and the influence of the by-products of degradation on the mobility and availability of other compounds and elements. At a simple conceptual level, a landfill can be viewed as a reactor vessel in which solid, water and gaseous inputs are subject to a variety of processes which produce solid, liquid and gaseous waste products. The reactor model for landfill processes is shown schematically in Figure 1, with the inputs, processes and outputs summarized briefly below.

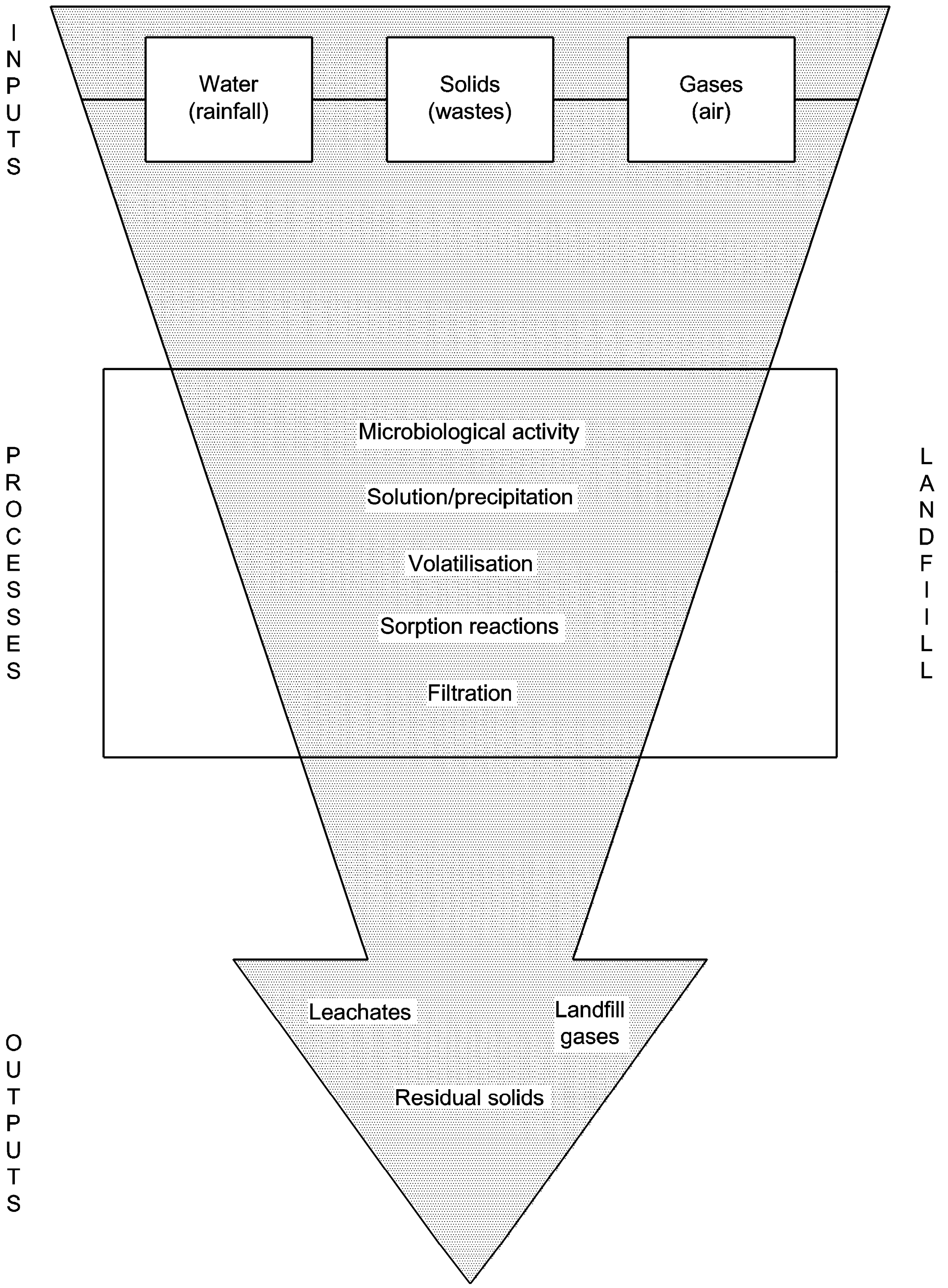


Figure 1 - Schematic representation of landfill processes

4.2 Inputs

4.2.1 Water

The principal water input at modern, managed, cellular landfill sites is rainfall which can gain direct access to waste during the filling phase for each cell and indirectly by percolation through capping and restoration layers after each cell is finished. Solid waste contains absorbed water and mixed household waste typically carries about 25 % water on a wet mass basis. Sludges contain about 10 % to 95 % water according to the extent of dewatering and drying treatment they have received (for information concerning national regulations about the water content, see Annex A).

4.2.2 Solids

Sludge, household waste and to a lesser extent commercial and industrial waste, contain putrescible materials which degrade within the landfill environment, giving rise to potentially polluting liquid and gaseous products. The process of degradation can create conditions in which other, non-organic compounds can pass into solution or enter a gaseous phase. About 20 % of household waste is rapidly biodegradable (putrescible) and a further 30 % more slowly degradable (cellulosic materials such as paper). In the case of sludge, about 30 % is rapidly biodegradable, 40 % progressively more slowly degradable and the remaining 30 % is non-degradable, inorganic ash. Articles 5.1 and 5.2 of the Landfill Directive (1999/31/EC) require that the biodegradable municipal waste deposited in landfill should be reduced progressively so that by 2016 the amount (by mass) of biodegradable municipal waste should not be more than 35 % of the mass produced in 1995. These targets will be achieved in part by composting and separation and recycling of waste. Sludge for landfill disposal should be stabilized (for instance, by aerobic or anaerobic digestion or by composting or lime stabilization or by acid treatment) to remove the rapidly biodegradable fraction and dewatered because liquid waste is unacceptable according to Article 5.3 of the Landfill Directive. However, under Article 2 (q), liquid waste is defined as any waste in liquid form including wastewaters, but excluding sludge.

4.2.3 Gases

The pore spaces of inert or slowly reactive solid waste arriving at a landfill normally contain a gaseous mixture close to that of the atmosphere, that is 79 % nitrogen and slightly less than 21 % oxygen, with the balance composed principally of carbon dioxide and trace amounts of other gases. The pore gases of putrescible waste can reflect rapid decomposition, in terms of reduced oxygen and increased carbon dioxide levels before deposition in the fill. The pore gases in and around sewage sludge will contain some methane and hydrogen sulfide (and other odorous compounds) as well as carbon dioxide. Sludge addition to an MSW landfill can accelerate gas production and stabilization of the landfill by a bioreactor effect (see [1]).

4.3 Processes

4.3.1 Microbiological activity

The breakdown of natural organic substances and certain man-made compounds is achieved largely through the activity of various microorganisms which consume the materials as food sources and, in so doing, release soluble and gaseous waste products and energy in the form of heat. The organisms can be aerobic, i.e. they require the presence of free oxygen (O_2 gas) for their metabolic processes or they can be anaerobic, when they gain their energy from the dissociation of compounds in the absence of free oxygen. Some organisms are strict aerobes or anaerobes and can operate only in one mode, but some microorganisms are able to switch from one form of respiration to the other. The breakdown processes can release directly into solution elements and compounds which form part of the original material, whilst waste products of this metabolism can encourage the dissolution of other materials, for example, by producing acidic conditions.

The incorporation of anaerobically digested sludge into a landfill represents an inoculum of bacteria which may accelerate anaerobic biodegradation within the landfill. This will be advantageous if the landfill is being run as a flushing bioreactor and by increasing the rate of stabilization within the landfill, the sludge can shorten the time to safe closure and completion of the landfill. Some authorities consider that if this concept becomes reality, the use of sludge will play an integral part in its design and operation (see [2])

4.3.2 Solution/precipitation

The direction of chemical reactions between the waste components and the liquids moving through the waste (leachate) is controlled by factors such as the relationship between the solubility of elements and compounds and the pH value and of their responses to Eh changes, that is the presence or absence of free oxygen (oxygenated systems have a positive Eh values, reducing systems a negative Eh). As an example, the solubility of many metals is increased as acidity rises (pH values fall to below 7,0), whilst iron is relatively soluble when reducing conditions are present (negative Eh value), but far less soluble in oxygenated environments (positive Eh). The physico-chemical conditions within landfilled waste change during the breakdown and stabilization process (described below) and elements and compounds which are dissolved at one stage in the lifecycle of a landfill can become immobilized by precipitation at another stage, and *vice versa*.

4.3.3 Volatilization

The conversion of liquids (or occasionally solids) to the gaseous state is encouraged by increased temperatures. Microbiological activity can raise the temperature within a waste mass from the average ground temperature of about 10 °C to values in the range 30 °C to 40 °C or more if the waste layer is very thick. Consequently, the gaseous mixture within the waste mass can contain not only the gases produced by the breakdown or organic matter, but water vapour and volatilized hydrocarbons, solvents and similar compounds derived directly from waste materials.

4.3.4 Sorption reactions

Two groups of processes can be involved:

- *absorption*, in which liquid is stored in the pores of the solids, but from which it cannot drain under gravity. The liquid and its dissolved content can be released from the pores if the material is compacted (squeezed) and the liquid can be removed from the pores by evaporation, leaving behind the originally dissolved components;

- *adsorption*, in which elements and compounds are immobilized by becoming attached to the surface of the solids. Many organic compounds in solution or emulsion will attach themselves preferentially to stable organic solids (humic substances, for example), whilst many clay minerals (and other minerals with layer-lattice molecular structure) exhibit the property of base exchange in which cations in solution (for example, metals, ammonium ions) exchange with other cations which form part of the mineral structure. The effect can be reversible so that a cation which has been removed from solution could be released back into solution if the physico-chemical conditions change.

4.3.5 Filtration

A landfilled mass of waste is a coarse, heterogeneous, granular deposit in which liquids and gases move through pore spaces. The liquids can carry particulates in the form of fragments of material detached by decay processes, precipitates and microbial organisms. Removal of particulates from transport by filtration in pore throats can take place, more particularly as the waste decays and collapse of the larger voids leads to compaction and a reduction in the average pore size. The movement of liquids in landfills is predominantly vertically downwards, in response to the gravitational field, and the blinding of pores in the lower parts of landfills contributes to the progressive reduction in hydraulic conductivity of waste with age and depth of burial.

4.4 Outputs

The principal outputs for a landfill containing biodegradable waste are summarized in Figures 2 and 3. An initial aerobic stage (Phase I) is short-lived. Aerobic bacteria begin the breakdown of organic materials and in so doing consume oxygen and release carbon dioxide and water. Aerobic degradation is metabolically vigorous and a rapid rise in temperature of the waste mass is possible. Once the free oxygen has been consumed, anoxic conditions set in (Phases II and III) and organically strong leachates are produced. The methanogenic bacteria which become active as the wastes move from Phase II into Phase IV are sensitive to pH and become inhibited at values below about pH 6,4. Waste which has partly degraded retains a significant buffering capacity and it is probable that methane generation in landfills involves a two-part process, with acetogenesis (production of acetic acid which the methanogenic bacteria can convert to methane, carbon dioxide and water) taking place within the more recently deposited waste and the methane production being carried out in zones of partially degraded materials with higher buffering capacity. In Phase IV, fully anaerobic conditions become established and the removal of carbon from the waste as methane and carbon dioxide in landfill gas becomes at least as important as removal in the form of dissolved organic compounds in the leachate. Finally, exhaustion of the biodegradable components allows the progressive re-establishment of aerated conditions (Phase V). At the end of this phase, the production of landfill gas and contaminated leachate ceases and the site becomes finally stabilized.

At the same time that carbon-based compounds are transformed into dissolved or gaseous components within the landfill reactor, inorganic materials contribute to the composition of the leachate (Figure 3). The variations in concentrations with time can be related primarily to their solution coefficients or be governed by changes in Eh/pH conditions within the waste. These latter conditions are strongly influenced by the microbiological activity in the waste. Examples of the behaviour of different types of contaminants can be illustrated by:

1) *chloride,* which is a mobile but persistent element. Maximum concentrations are likely to be reached during the earlier stages of stabilization as a result of direct dissolution and then to decrease with time through flushing from the wastes;

2) *ammonia,* which arises largely from the breakdown of proteinaceous material. High values are likely to be reached early in the life of the fill, but then decrease relatively slowly compared with chloride. The ammoniacal nitrogen forms an essential building block of the microbiological protein and is conserved and cycled within the waste. In Phase V, the ammonia concentrations decrease finally as a result of the extinction of anaerobic microbial activity. Residual ammonia is likely to oxidize to nitrate.

3) *heavy metals*, which are of generally low solubility in neutral or alkaline solutions. Maximum concentrations are likely to be recorded during the Phases II and III when high rates of fatty acid production lead to low pH (acid) conditions.

The composition of leachates is such that they can be both polluting and toxic. The principal environmental pollution threat in the short term arises from the high levels of dissolved organics which can deoxygenate waters and lead to the destruction of fauna and flora. The high concentrations of ammoniacal nitrogen pose specific threats to fish life. The processes and reactions that produce leachate are progressive and, consequently, the composition and strength of leachates change with time. The organic strength of leachate from fresh waste is greater than that from aged waste, and the ratio of total dissolved carbon to degradable carbon increases as waste ages and moves into phase III of degradation (Figure 2). However, many modern landfills evolve rapidly to phase IV in which a high proportion of the dissolved carbon is converted to gaseous components, with the result that the organic strength (measured as COD, BOD, TOC or Fatty Acids - (TVA or VFA)) decreases very significantly with levels of ammoniacal nitrogen remaining high.

All micro-organisms require water for metabolic purposes. Although some micro-organisms present within landfills are able to move actively through the waste mass, many forms are attached and only able to migrate through, and to colonize the waste mass, via water films. The distribution of bacterial populations in waste, as delivered to landfills, is non-uniform and heterogeneous. If the flux of water through the wastes is not sufficient to allow migration and general colonization by the micro-organisms, degradation can be only partial, with zones of waste remaining in an undegraded state for prolonged periods, but retaining a potential to degrade at some future time. Incorporation of sewage sludge, with its large population of microorganisms and its moisture content, can counter this effect.

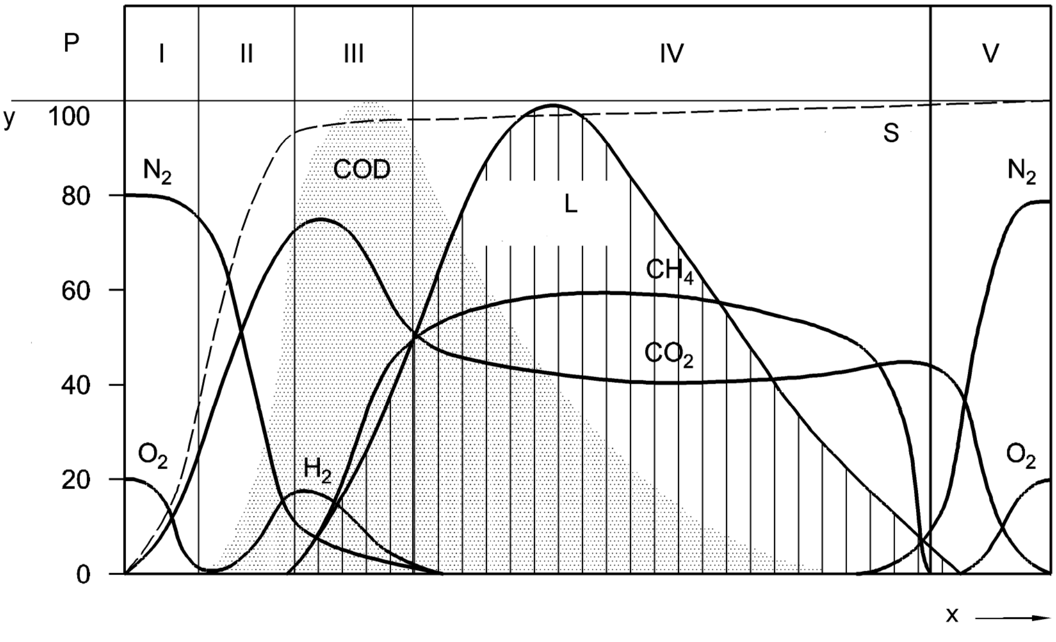
NOTE A nationwide survey of landfills for the UK Department of the Environment (see [3]) considered sites which included significant proportions of industrial waste and at which leachates from different parts of sites (and thus of different age) could mix. Very detailed analyses of leachates were made at selected sites and the results are summarized in Table B.1.

Compared with leachate and landfill gas, the data set describing the way in which residual solids change as the landfill processes progress to their end points is practically non-existent. However, it can be postulated that the end product of the process is likely to be a material similar in overall composition to that which forms naturally when inorganic and organic materials are deposited together. If that is the case, then the final material would be expected to comprise a compacted framework of resistant minerals (silicates, oxides, carbonates and sulfates) containing resistant organic residues (humic material). In the natural analogue, the resistates could be gravel, sand silt and clay grade minerals and rock fragments, including limestones (carbonates) with the organic material present as disseminated or aggregated peat or lignite. In the case of a landfill, the resistates could comprise natural (soils, sediments and rock included in the waste streams) and artificial (glass, brick/pottery, persistent plastics, rusted iron) forms. The biodegradable components of the waste are likely to show a range of rates of decay similar to those found for organic materials entering soils.

Compared with soil organic matter, studies by Jenkinson and Rayner (1977) (see [4]) indicate that there are few data on the biodegradability of the components of Municipal Solid Waste (MSW – household and commercial waste streams). However, research at the Polytechnic of East London (1992) (see [5]) suggested that the components of MSW could be classified in terms of biodegradability into:

- readily degradable – vegetable and putrescible and part of the fines < 20mm fractions ~18 % by mass;
- moderately degradable – parts of the vegetable, paper and card and fines < 20mm fractions ~12 % by mass;
- slowly degradable – textiles, most paper and card ~31 % by mass.

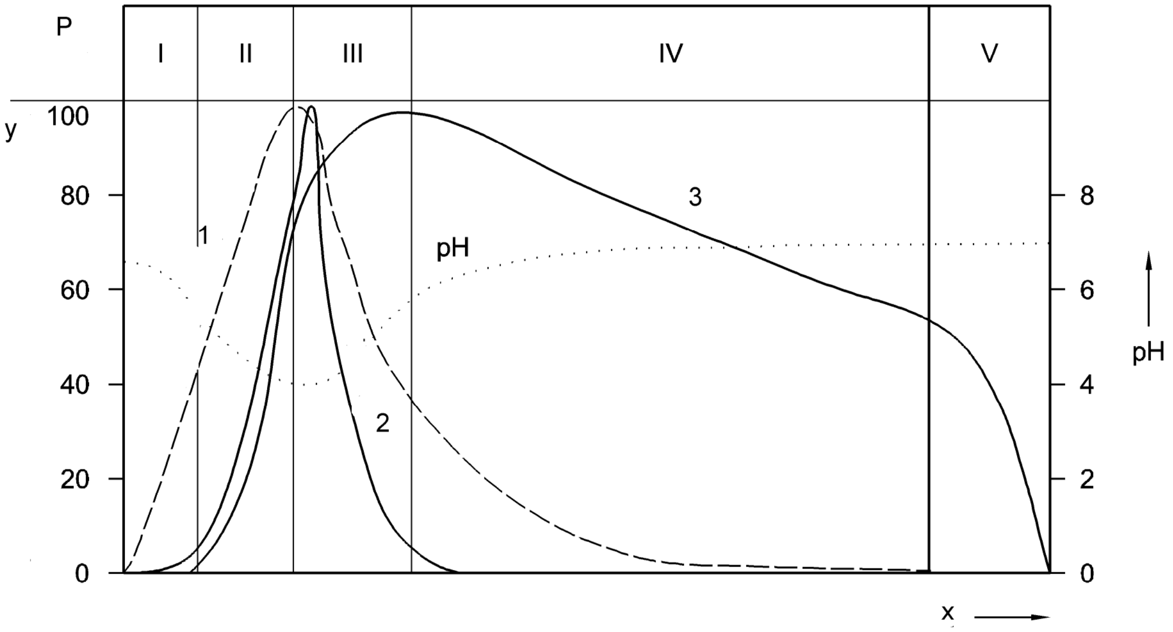
The remaining 39 % (unclassified, metals, plastics, glass, non-combustibles, fines < 20mm) were classed as inert. There is no formal direct correspondence between the classifications of soil organic material and MSW, but it is suggested that the readily degradable fraction of MSW can be considered equivalent to DPM, the moderately degradable to RPM and the slowly degradable part to PSO.



Key

x Time
y Percent by volume/maximum value
P Phase
L Landfill gas production
S Settlement

Figure 2 — Schematic representation of the evolution of organic components of landfill leachate and gas



Key

x	Time
y	Percentage of maximum concentration
P	Phase
1	Mobile persistent chloride
2	Heavy metals
3	Ammonia

Figure 3 — Schematic representation of the evolution of inorganic components of landfill leachate and gas

5 Current position and European perspective

The principal disposal routes for sludges are recycling to agriculture or other land, deposition in landfill or incineration or other energy recovery process. Whilst some of the ash from incineration may be used in civil engineering projects or the production of building materials, most of it is deposited in landfill. In 1996/98, landfill accounted for about 45 % to 50 % of the European Union production of sludges (see [6]). Use of landfill for whole sludge varied between Member States from 8 % to 90 % of sludge output (see [6]). Since the production of this CEN Technical Report, the implementation of the Landfill Directive in EU countries will have significantly modified the proportions of sludge treatment residues to landfill.

6 Legislative position

Disposal of sludges to landfill is controlled by Directive 1999/31/EC on the landfill of waste and additional legislation in individual Member States. Sludges from treatment of urban wastewater are classified as 'non-hazardous waste' but the ash from incineration of sludge can be classed as 'hazardous waste' if it contains 'dangerous substances': in this case, heavy metals. The concentrations of heavy metals (such as cadmium, mercury, lead, copper, nickel, zinc and chromium) which would cause either fly ash or bottom ash to be classified as hazardous are not specified. Fly ash from sludge incineration is likely to be classified as a hazardous waste in any event because of its caustic properties – pH value ca. 13.

The 'Waste Framework Directive' (91/156/EEC amending 75/442/EEC) includes the principle of the waste hierarchy which underpins waste management strategy within the EU. The hierarchy ranks the different waste management options in order of preference:

- reduction;
- reuse;
- recovery: recycling, composting and energy; and
- disposal in landfill or treatment in bioreactor.

For sludges, as for other waste, the aim is to minimize the quantity produced, to make best use of what is produced by recycling to land or energy recovery; with disposal to landfill being the least favoured option. However, landfill operation can be enhanced by sludge addition due to the bioreactor effect described above. Also, landfill represents a necessary alternative outlet for sludge should other options become unavailable on a temporary or permanent basis.

Sludges for landfill disposal should be stabilized and dewatered to obtain a sufficient consistency (see [7]) (for sewage sludge, a dry solids content of 25 % could be considered as an indicator of sufficient consistency or physical stability) according to national regulations so that the sludge is in the solid and not liquid phase and operation on the landfill site is safe

7 Economics

It is generally accepted that sludge treatment and disposal account for about half of the total costs of sewage treatment and disposal. This makes sludge management very expensive as the volume of wet sludge accounts for less than 1 % of sewage.

The most significant cost is for sludge treatment and this will increase further as more stringent hygiene standards are introduced. Dewatering and drying of sludges is also very costly, although savings made in the high cost of transporting wet sludge offset this. Transport costs are a major factor in the overall cost of sludge disposal.

Because of concerns about the sustainability of landfill disposal of organic wastes such as sludges and in order to encourage alternative recycling-based options, some Member States have introduced limits on organic matter content and/or 'landfill tax' which will make landfill disposal more expensive and less tenable in future.

The Andersen report (see [6]) compares the generalized treatment and disposal costs (complete route costs) for some management options. For each of these, the spread of costs is large and overlaps with those of other options due to the influence of local circumstances on investment and operating costs. As can be indicated, conventional treatment (digestion) and use in agriculture or disposal to landfill are the lowest cost options, although both can be more expensive than more technical solutions due to the high operating costs of small WWTPs and in the case of landfill where full site construction costs are included for mono-disposal. Composting, thermal drying and incineration are generally much more expensive than the basic options, but still have a wide range of costs, reflecting size of plant, type of technology, etc.

8 Treatment requirements

Sludge is one of the more difficult wastes to manage because in its untreated state it is initially in liquid form with a low consistency (dry solids content around 2 %), odorous and contains pathogens and contaminants.

Also, because of its origin, it has a public perception and acceptability problem. Many of these negative properties can be improved by application of the treatment options shown in Table 1.

See also CR 13714.

Table 1 — Treatment options for sludge

Aims of treatment	Options	Examples
Conditioning	Chemical	Iron salt addition Lime addition Polyelectrolyte addition Acid treatment
	Thermal	Hydrolysis
Separation of phases	Thickening	Thickener
	Mechanical dewatering	Belt press Filter press[a] Centrifuge
	Drying	Drying bed Drum dryer Disc dryer Solar drying
Conversion	Biological	Anaerobic digestion Aerobic digestion Composting
	Thermal	Pyrolysis/gasification Incineration Vitrification

[a] More appropriate system

Thickening and dewatering reduce the bulk of waste for disposal. For instance, if thickening can increase the dry solids (ds) content of a thin sludge or slurry from 2 % to 4 %, then there will be half the volume of sludge to deal with. Dewatering can take the process progressively further to produce a cake sludge of up to 40 % ds with a concomitant reduction of bulk. Drying can increase the dry solids content of the sludge to between 40 % and 95 %. In Mediterranean countries, drying beds can be a particularly cost-effective option in taking the sludge to 50 %+ ds and, if the drying sludge is periodically turned, achieving some stabilization of the waste and some removal of pathogens, if these were present. The heat drying processes require a substantial energy input, but if a dry solids content of 90 % and more can be achieved, then there is maximum bulk minimization and a dry handleable product which can be stored, is pasteurized and is suitable either for landspreading, use for energy recovery or landfill.

Anaerobic or aerobic digestion, which includes composting, are processes used to stabilize organic waste by breaking down the readily degradable organic matter it contains. In the case of sludges, anaerobic digestion achieves a reduction of volatile solids content of around 35 % to 40 % and produces methane which can be collected and used as a fuel. Apart from achieving some minimization of the waste, stabilization reduces odour potential and numbers and infectivity of pathogens if these were present in the waste. Exposure to around 40 °C should remove plant pathogens, and to 55°C to 60 °C animal and human pathogens, although the effect is time-temperature dependent.

Sludge for landfill disposal should be stabilized by biological treatment, composting or liming or by acid treatment and dewatered to obtain a proper consistency so that the sludge is in the solid and not liquid phase. Drying is a further option. Sludge to be landfilled is sometimes mixed with mineral products such as lime to give a high degree of chemical and physical stability. Such treatment might be necessary to ensure safe disposal of chemically contaminated sludge or to provide physical stability at sludge monofill sites.

Solids from the preliminary treatment of wastewater may also be disposed of to landfill. These materials are screenings, grit and scum. Screenings are the solids in the raw wastewater, which are removed by racks or bar screens at the head of the works. They are unpleasant, odorous and are usually compacted before disposal to landfill or treatment by incineration.

9 Operational aspects

9.1 General

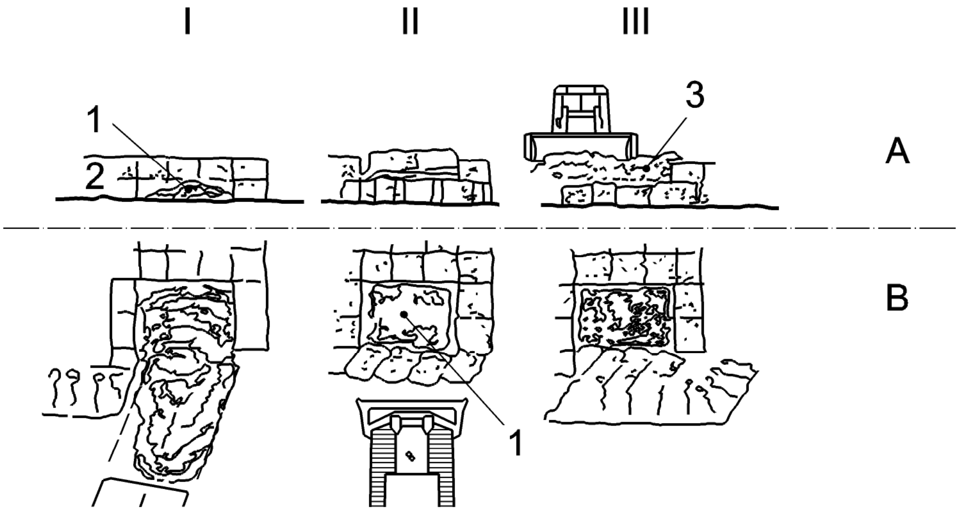
When allowed, sludge is moved to landfills taking municipal solid waste in which it makes up 10 % to 40 % of the fill. Admixture of the sludge and waste is achieved either in trenches or in thin layers between the emplaced waste. Some examples of typical operations are described below.

9.2 Co-disposal of sludges and baled municipal waste

The high-density bales, each weighing approximately 1,2 t and measuring 1 m x 1 m x 1,5 m, are delivered to the landfill in batches by articulated tractor and trailer units. They are off-loaded and stacked, two high, in a similar fashion to building blocks, by wheeled loading shovels with fork attachments.

It is not recommended that the bales are placed onto a thin layer of sludge because the loading shovels become contaminated and have subsequent difficulty with traction. Best practice is to form a series of bays, using the bales to create the side and rear walls, into which the sludge can be deposited. The sludge delivery vehicle is then able to reverse into the bay and deposit its load.

Each bay, which is contiguous with the operational working face, comprises an area of 3 bales wide by 2 bales deep and is able to contain approximately 20 t of dewatered sludge cake of 28 % ds. The filling sequence I to III is shown from Figure 4.



Key

I	Sludge delivery
II	Containment
III	Closure and tracking
1	Sludge
2	Bales
3	Broken bales

Figure 4 Co-disposal of sludge and baled municipal waste

When filling, the open end of the bay is closed off by a further 3 bales. By manoeuvring these bales towards the rear of the bay, using the on-site mobile plant, the sludge is squeezed until its upper surface is level with the top of the adjacent lower layer of bales. The cell is then covered by pushing whole and broken bales onto the surface of the sludge and tracked in using a crawler bulldozer.

The bales which form the cell restrain the movement of the sludge, particularly when the top covering of waste is applied and enable the upper surface to be consolidated, giving relatively stable ground conditions.

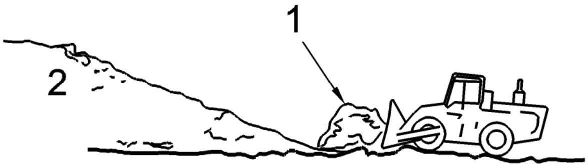
Using this technique, it is possible to encapsulate 20 t of wet sewage sludge with around 80 t of baled municipal waste, with minimal contamination of on-site mobile plant. This gives a waste to sewage sludge ratio in the order of 4/1. For operational reasons, however, it is advisable that the cells be dispersed as widely as possible across the landfill area to avoid compounding the possibility of creating localised ‘soft spots’. As such, the optimum waste to sludge ratio for this kind of operation is probably about 10/1.

9.3 Co-disposal of sludges and loose municipal waste

Normal practice with loose municipal waste is for the waste from the collection vehicle to be deposited at the crest of the landfill tipping face. It is then subsequently pushed over the inclined face and consolidated by means of successive passes of a mobile steel-wheeled compactor. Using this method, it is possible to achieve an emplaced density of up to 1 t/m^3. Where sewage sludge is to be included, experience has shown that the optimum method of incorporation is apply thin layers of sludge between successive lifts of controlled waste.

The sludge delivery vehicle deposits its load at the foot of the working face. Using the blade of the mobile compactor, the sludge is spread evenly in a thin layer approximately 0,25 m thick over the underlying waste. Loose refuse is then pushed down the inclined face onto this layer, always ensuring that there is sufficient thickness to prevent the sludge forcing its way to the surface and contaminating the compactor. The minimum thickness of loose waste required is usually 1 m resulting in lower achievable emplaced densities. This sequence of operations shown in Figure 5 a) to Figure 5 d).is repeated on the adjacent landfill area until the entire sludge load has been covered. Although the mobile compactor generates very high ground pressure point loading across the landfill surface, sludge should not come into contact with its wheels except during initial spreading, provided that there is sufficient thickness of overlying refuse cover (see [8]).

Figure 5 a) - Sludge delivery

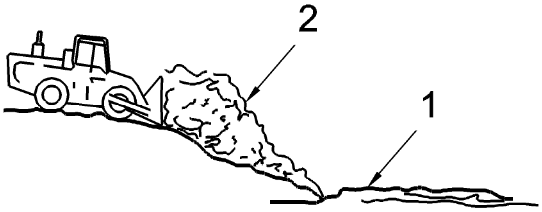


Key

1 Sludge

2 Controlled waste

Figure 5 b) - Single pass by compactor to spread sludge



Key

1 Sludge

2 Controlled waste

Figure 5 c) - Compactor used to push controlled waste from above

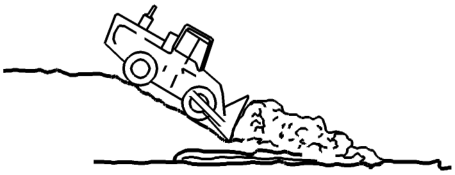


Figure 5 d) - Second load to cover and consolidate

Using this technique, it is possible to co-dispose of municipal waste and sludge in a ratio of 3/1. Compared with the baled waste operation, there is not the same restriction on the location of the sludge disposal area provided that the thickness of the sludge layer is acceptable and covered by sufficient municipal waste. However, seasonal weather conditions have an influence in determining acceptable quantities of sludge additions.

9.4 Monofills for sludge disposal

These are landfills dedicated to receive sludge and cover material (soil or inert waste) as opposed to co-disposal with municipal solid waste, which is the option used predominantly for landfilling of sludges. Daily cover of the emplaced layer of sludge keeps vectors of pathogens (flies, birds etc) away from the sludge and helps to prevent odour nuisance. In monofills, insufficient oxygen is available for aerobic decomposition and the sludge is slowly degraded by anaerobic decomposition. Sludge of high dry solids content is required to achieve acceptable physical stability and bearing strength and to minimize leachate production. Pre-treatment of the sludge with lime or other mineral material may be needed to provide the necessary physical stability. Use of sludge treated in this way can preclude the requirement for daily cover of the sludge layer (see [9]).

9.5 Sludge in cover materials

9.5.1 Temporary cover

A possible part of landfill operation could be to cover the landfilled waste at the end of each working day, or at more frequent intervals if necessary, with a layer (about 0,15 m) of soil or inert material to control disease vectors, fires, odours, blowing litter and scavenging without presenting a threat to human health and the environment. A sludge/soil mixture in an approximately 1/1 ratio can be a suitable material for daily cover of the landfill surface. In a sludge/soil mixture operation, sludge is mixed with soil and applied as daily cover or as cover over completed solid waste fill areas. If a sludge/soil mixture operation is planned, an area should be reserved at the planning/design stage for sludge/soil mixing. This area should be of sufficient size and have sufficient soil available for preparation of the mix. Also, a pasty sludge can create an impermeable cover, which is not appropriate for the landfill (an impermeable cover can prevent or slow down the waste degradation), in which case mix the sludge and soil well.

Sewage sludge without soil can be a suitable daily cover material if it has a solids content of at least 50 % and has undergone stabilization treatment to reduce its content of degradable organic matter. Sludge with these characteristics has been attributed with the following advantages as cover material:

- it has a high moisture absorption capacity, thereby helping to control insects, rodents and other vectors that thrive under wet conditions;
- like soil, it has a high odour-absorbing capacity;
- like soil, it acts as a physical barrier to control blowing litter and improves the appearance of the landfill;
- it can reduce the fire hazards associated with municipal solid waste landfills;
- it helps to reduce the potential for leachate contamination of ground and surface water.

9.5.2 Final cover

When a municipal solid waste landfill has reached the end of its useful life, it receives a final cover to minimize the flow of water into the closed landfill and to provide a substrate for vegetative cover. This normally consists of an infiltration layer of about 1 m of clay or similar material, covered in turn by 1 m of soil. Digested sludge with a dry solids content of at least 20 % is very suitable for inclusion with soil in the top layer at a soil/sludge ratio of about 1/1 (the ratio depends on the sludge and on the soil nature). The sludge supplies organic matter and slowly released nitrogen and phosphorus which encourage sustainable soil development and plant cover.

10 Environmental aspects

10.1 General

The key environmental aspects of sludge disposal to landfill have been identified as:

- emissions of polluting components to water (surface water and groundwater), air and soil;
- shortage of suitable land;
- disturbance of landscape.

10.2 Leachate

The disposal of dewatered sludge to landfill introduces liquid into the waste and affects the overall site water balance. Resultant leachate volumes are not only dependent upon the quantities of sludge disposed of, but also its ratio to controlled waste. In order to minimize the increase in leachate production, the ratio of sludge to municipal solid waste in the landfill should not exceed 1/10. At this rate of incorporation, any effect of sludge on leachate quality is also likely to be minimal.

Whilst sludge might be expected to have a negative effect on the quality of leachate from a municipal solid waste landfill, trials would indicate that co-disposal with sludge improves leachate quality. Table 2 gives, as an example, some data from Stamm and Walsh (see [9]) from a four-year landfill simulator study evaluating co-disposal, MSW-only disposal and sludge-only disposal. In addition to the effect on sludge quality, more contamination was released about one year earlier from the co-disposal cells than from the other treatments.

Table 2 — Leachate values from landfill test cells averaged over four years

Parameter	Co-disposal	MSW only	Sludge only
COD (mg/l)	2 889	22 453	2 258
TOC (mg/l)	903	4 640	737
pH	7,1	6,4	6,2
Volatile acids (mg/l)	868	7 434	1 213
Volatile solids (mg/l)	2 171	7 659	5 555
Specific volume in litres per kilogram per month (l/kg/mo)	0,03	0,03	0,07

From operational trials, Hill (1991) (see [8]) reported that sludge incorporation into an MSW landfill caused a reduction in the concentration of some Fe and Mn metals in the leachate, but there was a corresponding increase in ammoniacal nitrogen and total phosphorus levels. Incorporation of sludge at a rate of 1/10 with MSW has little effect on concentrations of heavy metals in leachate because of the small quantity of sludge and relatively high concentrations of heavy metals in MSW (see [10]). In another trial, when the sludge (38 % ds) to MSW ratio was 1/3,4, the influence of sludge was pronounced in the first 2 to 3 years. The sludge had a stabilizing effect on the processes in the landfill body, with lower COD and VFA concentrations and a higher pH value in the leachate. As a result of the higher pH value, the concentrations of heavy metals in the leachate were decreased in spite of larger quantities of heavy metals in the landfill body.

10.3 Methane generation

The methane generated in a landfill is a renewable energy (see Directive 2001/77/EC) and the use of renewable energy should be promoted to reach 22 % in 2010 and, consequently, biogas production should be favoured

Trials have shown that the addition of sludges to municipal solid waste on a co-disposal basis in landfills enhances the decomposition process as measured by methane generation (Stamm and Walsh see [9]). It was found that co-disposal test cells in the trial generated methane much sooner than the MSW-only cell which is significant because methane collection and treatment is much more effective in the early life of a landfill as compared to after its closure. In operational trials (see [8]), it appeared that the addition of sludge to MSW (ratio 1/10) had a catalytic effect on the decomposition process, accelerating the onset of methanogenesis. As a consequence, methane concentrations of around volume fraction 50 % were evident within two months of the waste and sludge emplacement. By comparison, in sites taking MSW only, this state of decomposition can take over twelve months to achieve The addition of sludge can facilitate efficient methane collection during the operational life of a landfill and reduce the time needed to achieve full stabilization and safe closure of an MSW landfill. Methane production can be effectively predicted (see [11]). Accelerated methane production cannot be achieved with lime-treated sludge, nor with water treatment works sludges which are largely inert with a low organic matter content.

10.4 Void space and settlement

In co-disposal operations, sludges are usually incorporated as a cake material of more than 25 % ds. If applied in alternate layers of sludge (about 0,25 m) to MSW (about 1 m) as in 10.3 above, the sludge will use up very little void space after compaction because it will be squeezed into the gaps and voids within the MSW. The incorporation of sludge will, however, cause some reduction in the emplaced density. Where the sludge is incorporated with MSW in the form of high-density bales (10.2 above), then low spots corresponding to sludge ‘pockets’ can occur. This is undesirable especially when the site is reaching final contour level. Consequently, it is recommended that deposits of sludge are not made in the final 5 m of a site being filled with baled MSW. However, the addition of sewage sludge to other wastes induces an acceleration of the biodegradation and correlatively an acceleration of the compression of the waste bed. Therefore, the final density of the landfilled waste will be higher.

10.5 Other environmental factors

10.5.1 Odour

Sludge for landfill will have been through a stabilization treatment which should reduce its odour. Covering the sludge with MSW immediately after its delivery to the site can minimize odours at the landfill site or, if this is not possible, it should be stockpiled for as short a time as possible. Odour nuisance can be of major concern to any nearby residents affected by it.

10.5.2 Contamination of mobile plant

The wheels, tracks and front blade of mobile plant can become contaminated with sludge despite careful site husbandry (10 above). Facilities should be available for machines to be quickly and easily washed and for the wash water to be disposed of safely.

10.5.3 Fire and dust

Undigested, dried sludge has a calorific value similar to that of low grade coal, so there is potential for it to catch fire. Dried sludge can generate dust. Hosing and sprinkling equipment should be available on sites where these problems could occur. Most sludge moved to landfill will be stabilized sludge cake with an appropriate consistency (for sewage sludge, a dry solids content of 25 % could be considered as indicator of sufficient consistency or physical stability) and should not cause a dust or fire problem. Sludges of greater than 90 % dry solids should not be placed in landfills in powdered form due to the risks of dust escape and creation of potentially explosive conditions. Granular or pelleted forms of greater than 90 % dry solids are, however, acceptable. Also, there can be risks regarding the transport and storage of powdered materials.

Annex A
Current landfill legislation in EU Member States

Italy

Landfill sites are still regulated in Italy according to the Intergovernmental Decree of 27July1984, as the European Directive 1999/31/EC had not yet been brought into force. It is expected that this will happen quite soon as there is available a draft including four annexes on criteria and requisites for construction and operation, on acceptability of wastes, including sampling and analyses, on control and monitoring procedures in operation and after-care phases, and finally on authorization request and permit.

Three different types of landfill sites are included in the draft: landfill for inert waste, landfill for non-hazardous waste and landfill for hazardous waste. Specific conditions regulate the acceptance of asbestos waste in the landfill sites for non-hazardous and for hazardous waste.

DECREE OF 27 JULY 1984

Classification of landfill sites

Landfill sites are classified in Italy into the following categories:

i) landfill sites in category I are for.

- urban solid waste and other similar solid waste;
- non-hazardous sludges from sewage treatment plants which have been stabilized and well dewatered, or other sludges with similar characteristics. Sludge is considered “well dewatered” if it can be shovelled;

ii) landfill sites in category II are further classified into:

- type A which is for:
  - solid waste from construction and demolition activities;
  - ceramic materials;
  - glass materials.
- type B which is for:
  - special waste which is neither toxic nor noxious, and whose concentration of selected hazardous organic compounds does not exceed 1/100 of the limits for classification as toxic and noxious waste;
  - special solid waste, also toxic and noxious, as it contains heavy metals, but in compliance with the leaching test (leachate within the limits of the effluents from wastewater treatment plants of productive installation). If the permeability of the ground at the landfill site is very low, the toxic and noxious solid waste is accepted as long as the leachate quality does not exceed the above-mentioned standards by 10 times;
  - solid waste with asbestos powder and/or fibre in concentrations not greater than 10 000 mg/kg;
- type C which is for:

- toxic and noxious solid waste, except for that containing selected organic hazardous compounds in concentrations higher than ten times the standards. The following types of waste are not accepted at the type C landfill site:
  - flammable waste whose ignition temperature is lower than 55 °C;
  - waste which is dangerously reactive with water;
  - liquid waste;
  - solid infectious waste;

iii) landfill sites in category III are for:

- any solid waste which cannot be accepted in the other categories and types of landfill sites.

Technical criteria for category landfill sites

The site shall be far away from water resources and from any flood water drainage or river bed.

The sites shall be geologically stable.

The leachate from the sites shall not cause any pollution of surface or ground water.

When lining is used, the following criteria shall be followed:

- the bottom of the site shall be at least 1,5 m above the maximum ground water table level;
- a layer of soil (clay) of at least 1 m with a permeability of less than 10^{-6} cm/s shall be located under the lining system;
- the leachate from the site shall be collected and treated;
- the biogas shall be collected and recovered, or burnt by means of torches;
- the equipment for leachate and biogas collection and treatment shall be in operation even after the landfill site is filled up.

Finland

In Finland, liquid waste shall not be disposed of on landfill. The ban does not relate to sludge. However, sludge is not defined accurately. It can be interpreted so that sludge in liquid form is banned.

Regulations concerning pretreatment and biodegradable waste on landfill will be enforced from 2005-01-01. However, pretreatment (which could be interpreted as stabilization and dewatering of sludge) of landfilled waste is compulsory for landfills established after 2002-01-01.

France

The regulation dates from September 1997,

For sludge:

- since July 2002, a waste shall be qualified as an "ultimate waste": this means a waste which cannot be valorized in the technical and economical conditions applicable is eliminated;
- consistency (sludge dry content: greater than or equal to 30 %);

- in these conditions, these sludge can be landfilled in a landfill which accepts municipal waste (Class 2 landfill).

For sludge treatment residues (i.e. residues from sludge incineration):

- if the residue is considered as hazardous, it is accepted in a landfill for hazardous waste (Class 1 landfill);
- the waste shall be stabilized. If it is not stabilized (leachates from waste do not respect some conditions), the waste shall undergo a stabilization treatment.

Germany

According to the TASi (*Technische Anleitung Siedlungsabfall*), now incorporated in German waste law, it is concluded that any material i.e. also sludges from sewage treatment with a percentage higher than 5 % organic compounds are not allowed on any landfill. This means that sludges shall only be brought to landfill after pretreatment by incineration as ashes. There are some exceptions for sludges, such as composting in amended soils as cover.

Switzerland

No organic waste shall be disposed of on landfill.

Annex B
Composition of leachates

The mean leachate compositions are given as an example. They are based on very detailed analyses of leachates from UK landfills given in [3] and they are summarized in Table B.1.

Table B.1- Mean leachate compositions (from selected sites in the UK)

Parameter	Mean value Domestic/commercial waste only	Mean value Domestic/commercial + Industrial waste
pH	7,2	7,4
Conductivity (µS/cm)	6 690	10 360
Alkalinity (as $CaCO_3$) (mg/l)	3 100	4 240
COD (mg/l)	3 280	2 620
BOD_{20} (mg/l)	>740	>1020
BOD_5 (mg/l)	>690	>1210
TOC (mg/l)	720	680
Fatty acids (as C) (mg/l)	305	115
Kjeldahl – N (mg/l)	450	680
Ammoniacal – N (mg/l)	430	640
Nitrate – N (mg/l)	3	1
Nitrite – N (mg/l)	0,2	0,2
Cyanide (mg/l)	<0,5	<0,05
Sulfate (mg/l)	150	110
Phosphate (mg/l)	2,5	4,0
Chloride (mg/l)	970	1 920
Boron (mg/l)	3	17
Sodium (mg/l)	725	1 320
Magnesium (mg/l)	140	180
Potassium (mg/l)	450	590
Calcium (mg/l)	290	160
Vanadium (mg/l)	0,5	1,2
Chromium (mg/l)	0,06	0,10
Manganese (mg/l)	2,6	0,7
Iron (mg/l)	71	15
Nickel (mg/l)	0,08	0,1
Copper (mg/l)	0,03	0,05
Zinc (mg/l)	0,4	1,0
Arsenic (mg/l)	0,0006	0,01

Parameter	Mean value Domestic/commercial waste only	Mean value Domestic/commercial + Industrial waste
Cadmium (mg/l)	<0,1	0,01
Tin (mg/l)	6,7	2,4
Mercury (mg/l)	< 0,00001	0,00002
Lead (mg/l)	0,1	0,1
Aluminium (mg/l)	< 0,1	< 0,1
Silicon (mg/l)	12	11
Pesticides		
Gamma-HCH (lindane)	3,4 µg/ l	
Organophosphorus pesticides Dichlorovos	1,6 µg/ l	detected in 43 % of samples
Atrazine	4,0 µg/ l	detected in 83 % of samples
Simazine	3,6 µg/ l	detected in 67 % of samples
Solvents		
Hexachlorobutadiene	0,08 µg/ l	detected in 7 % of samples
1,2,3- trichlorobenzene	0,58 µg/ l	detected in 17 % of samples
1,2,4- trichlorobenzene	0,32 µg/ l	detected in 7 % of samples
1,3,5- trichlorobenzene	0,19 µg/ l	detected in 20 % of samples
Dioxins and furans		
PCB as Arochlor 1260	0,08 µg/ l	detected in 20 % of samples

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[16] Directive 1999/31/EC on the landfill of waste.

[17] Directive 2001/77/EC on renewable energy.

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