Technical report No 38

Dangerous substances in waste

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Contents

Executive summary

- The environmental problems caused by dangerous substances are acknowledged by the Council Resolution of 24 February 1997 on a Community Strategy for Waste Management, where the Commission is requested to collect information on those dangerous substances and materials in waste which cause special problems in Member States and to bring forward recommendations for measures to deal with these problems.
- One of the general objectives of work by the European Topic Centre on Waste is therefore to provide documentation on dangerous substances and materials in waste which cause special problems in Member States and to show how the environmental impact from some of these substances and materials can be minimised by means of for example material substitution, good housekeeping, clean technologies, better source separation and handling etc.
- This report focuses specifically on environmental risks associated with the main final disposal technologies, landfilling and incineration. The main objective of this report is the analysis of these technologies and the description of the related emissions, the evaluation of dangerous substances and the selection of relevant waste streams, which are responsible for the release of these substances. The geographical scope is EU15. The latest estimates available for emissions to air at European level were for 1990, the major data sources being CORINAIR and the German Environment Agency (Umweltbundesamt). Emissions data for emissions to water and soil were obtained from literature and Internet searches and from interviewing several experts.
- A methodology is presented for the evaluation of the environmental relevance of dangerous substances in waste streams treated by landfilling or incineration. Based on this evaluation waste from electrical and electronic equipment (WEEE) which contributes to the emission of dangerous substances was selected for further investigation. This evaluation and selection was done as far as possible by scientific methods. However, the data available at both national and European level are too weak to base decisions on pure scientific methods alone. Therefore this analysis was additionally based on the experience of relevant experts and of representatives from national authorities.
- The key emissions at European level from incineration were identified to be organic micro-pollutants, particularly dioxins and furans, and volatile heavy metals, particularly cadmium, mercury and lead, where incineration was still an important generating source. For landfill, the key emission at European level is methane, an important greenhouse gas, with other emissions contributing to impacts at local level.
- Interviews with experts and literature reviews suggested that the relative contribution of emissions from waste treatment to total emissions from industry and agriculture in 1999 is most likely lower than indicated by the 1990 data and will decrease in future due to the improvement of cleaning technology for incineration and the reduction of organic inputs to landfill. This process will be enforced by the implementation of EU Directives in national legislation.
- Having considered various waste streams and having consulted with the EEA, the Commission (DG Environment) and Eurostat, it was decided that further studies on the flow of dangerous substances in waste should concentrate on waste from electrical and electronic equipment (WEEE) for the following reasons:

- this waste stream contributes to the production of several of the dangerous substances identified in this report by virtue of the composition of the products contained within the stream;
    - the composition of the waste stream is reasonably well defined, since it is the same as the products from which the stream arises;
    - where insufficient data exists on waste generation, waste quantities can be estimated from production data;
    - the waste stream is of particular relevance to future waste planning because of the hazardous substances contained within it and the increasing amounts that are being generated; and
    - there is political interest in this waste stream as reflected in a EU draft Directive on WEEE

- The next step will be the development and presentation of a substance flow analysis methodology to track the flow of dangerous substances through the waste chain and their final release to the environment. This methodology will be tested by applying it in an exemplary fashion to the WEEE stream so that measures to reduce environmental impacts from the treatment of this waste stream can be identified and reported.

1. Introduction

1.1. Objectives

The environmental problems caused by dangerous substances are acknowledged by the Council Resolution of 24 February 1997 on a Community Strategy for Waste Management, where the Commission is requested to collect information on those dangerous substances and materials in waste which cause special problems in Member States and to bring forward recommendations for measures to deal with these problems.

One of the general objectives work by the European Topic Centre on Waste is therefore to provide documentation on dangerous substances and materials in waste which cause special problems in Member States and to show how the environmental impact from some of these substances and materials can be minimised by means of e.g. material substitution, good housekeeping, clean technologies, better source separation and handling etc.

1.2. General approach

In line with the general objective set out above the system boundaries are defined as shown in Figure 1.1. The scope of the study comprises the whole 'waste chain' from the point at which the waste is produced to its final disposal. All emissions from the waste chain will be considered with the exception of transport.

Emissions that are related to the production process itself and/or previous processes, e.g., production of raw and process materials, are outside the scope of the study. Therefore, while an approach similar to life cycle assessment is proposed in this report, the approach is not strictly speaking a life cycle assessment since this would take account of emissions resulting from raw material usage and production processes as well as emissions resulting from waste treatment.

The approach will include an analysis of factors such as: reduction of the amount and the harmfulness of waste through substitution of process materials, the implementation of resource saving production processes, reduction of waste quantities by sorting and separating material for reuse and recovery and reduction of emissions by improvement of the treatment technology (s. Figure 1.1).

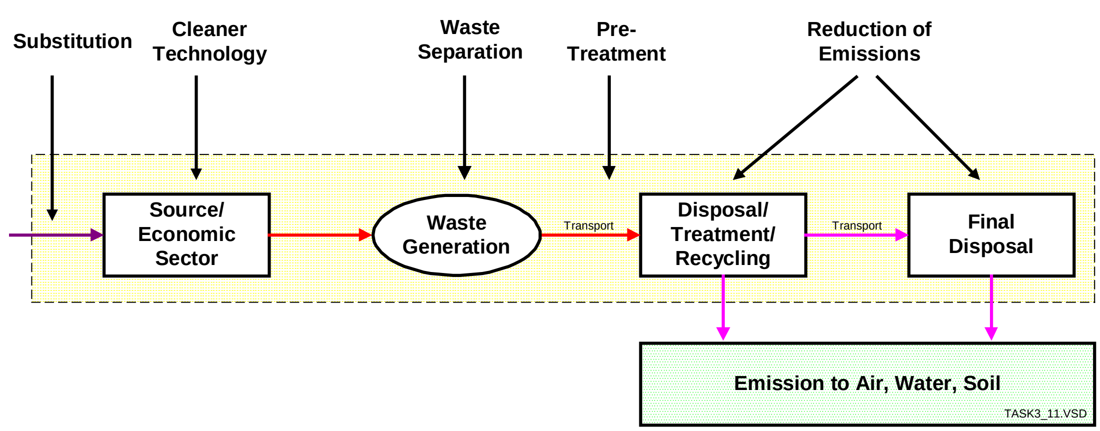

Figure 1.1: Scope and system boundaries of the study

The work will proceed on a step-by-step basis and according to the progress made, several reports will be published:

1. **This report** evaluates emissions from landfill and incineration (final disposal) and identifies specific dangerous substances and relevant waste streams that merit further investigation.
2. Next step will be the development and presentation of a methodology for substance flow analysis to track the flow of selected dangerous substances through the waste chain and their final release to the environment.
3. Finally, this methodology will be tested by applying it in an exemplary fashion to a relevant waste stream so that measures to reduce environmental impacts from the treatment of the waste stream can be identified and reported **.**

The results of step two and three will be published in subsequent reports.

1.3. Scope of this report

This report focuses specifically on environmental risks associated with the main final disposal technologies, landfilling and incineration. The main objective of this report is the analysis of these technologies and the description of the related emissions, the evaluation of the environmental relevance of dangerous substances and the selection of relevant waste streams, which are responsible for the release of these substances.

Chapter 2 presents an analysis of the major environmental risks associated with these technologies. Information on legal standards for landfilling and incineration in the consortium countries and regions is provided in Annex A and B.

In chapter 3 a methodology is presented for the evaluation of dangerous substances in waste streams treated by both landfilling and incineration. Based on this evaluation a waste stream which contributes to the emission of dangerous substances is selected for further investigation. This evaluation and selection has been done as far as possible by scientific methods. However, the data available at both national and European level are too weak to base decisions on scientific methods alone and this analysis was additionally based on the experience of relevant experts and of representatives from national authorities.

2. Environmental risks associated with the major waste treatment technologies

Waste production is one of the most revealing indicators of the interaction between human activities and the environment. Increased production and consumption results in increased production of waste. Concerns over the environmental impacts of the increasing volume and toxicity of waste have grown dramatically in the last two decades. Improper management of waste has caused numerous cases of contamination of soil and groundwater and threats to health of the exposed population. Environmental impacts of increasing waste volumes are strongly influenced by management methods and practices.

Waste disposal practice has, historically, followed the path of least resistance. Several factors have driven waste onto and beneath the earth's surface: The factors include the relatively low cost of land and land disposal procedures, the low capacities of other disposal technologies and last but not least environmental legislation at both European and national level whose principal objective was the protection of single media such as water quality and air quality which tended to shift the environmental burden away from these media and onto land.

Despite the increasing emphasis on waste prevention strategies, waste quantities have continued to increase. Landfill and incineration are the predominant practices in waste management within the region of 60 % and 68 % of municipal and hazardous waste in OECD countries, respectively, consigned to landfill (see Figure 2.1). However, this masks major differences between countries. For instance, in the UK 75 % of municipal waste is landfilled while the percentage of waste sent to landfill in Sweden is 30 %.

This chapter focuses specifically on emissions and environmental risks associated with landfilling and incineration and includes information about the major waste streams consigned to both landfill and incineration. This is presented with a view to providing some context for the evaluation procedure described in Chapter 3.

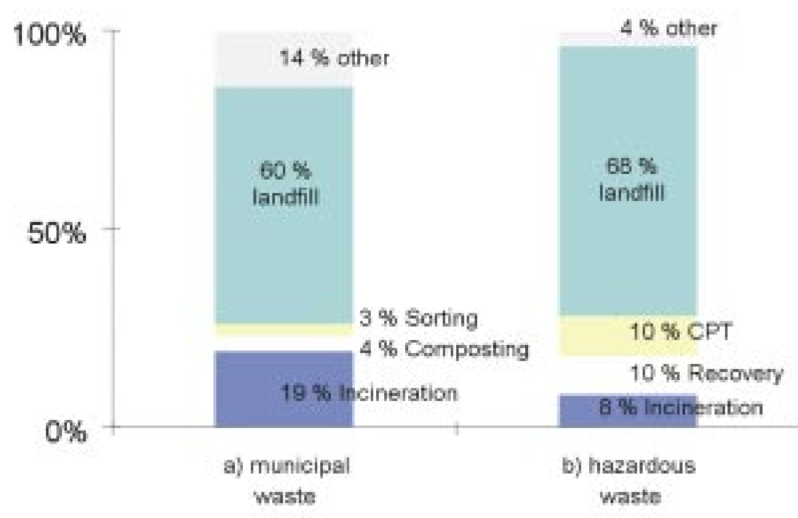

Figure 2.1: Management of waste in OECD Europe, Source: Yakowitz, 1992

2.1. Emissions from landfill

Generally speaking, landfills receive many different kinds of waste material. This is particularly true for landfills that receive municipal waste. For convenience sake, waste that enters landfills can be considered under a number of component types, each of which has specific implications for the emissions likely to arise. These are:

1. Specific organic components (SOC), e.g. organic solvents and methane;
2. General organic matter (GOM): all sorts of organic materials of biological origin which are easily degraded under conditions prevailing in landfills, e.g. wood, paper, food, fat, sugar;
3. Inert Components: heavily degradable polymers, e.g. PVC, PET and geological materials such as clay, sand and stones;
4. Metals: e.g. Fe, Cd, Cu, Pb, Ni, Zn;
5. Inorganic non-metals.

The relevance and general behaviour of these components, under conditions prevailing in a typical landfill, is summarised in Table 2.1. For instance, specific organic compounds are of interest due to the fact that many of them are potentially toxic to either human health or ecosystems. General organic matter will tend to degrade under typical landfill conditions giving rise to the production of methane and carbon dioxide and the production of water soluble organic compounds that can cause pollution of surface and groundwater. Heavy metals are also of interest due to their toxicity potential.

		behaviour in		
Component	**interest**	**Landfill**	**gas combustion plant**	**leachate treatment plant**
SOC	potential human toxicity	depending on the individual nature:		
Specific organic components e.g. organic chemicals (benzene, phtalates, phenols) more than 100.000 substances		partly/fully degraded; evaporate	totally mineralised/ passing unaffected/ partially combusted	depending on the treatment technology : adsorbed/leach out
GOM General organic matter of biological origin (e.g. wood, paper, fat) is decomposed into three main products: CH_4, CO_2 and dissolved organic matter. Since GOM originates from biological activity the emitted CO_2 is therefore considered to be neutral with respect to global warming.	Formation of methane	99 % of C is emitted as gas (CO_2, CH_4); 1 % is as unspecified matter dissolved in the leachate	Methane is completely mineralised to CO_2 and water	assumed to be biodegradable and non volatile
Inert Components all substances, which remain intact in the landfill during a long period (e.g. heavily degradable polymers PVC, PET, geological materials as sand, clay)	occupy space	no evaporation		do not leach out
Metals (e.g. Fe, Cd, Cu, Ni, Zn etc.)	potential toxicity	only Hg and Cd evaporate; emission is determined by sorption, precipitation and complex formation; metals are emitted very slowly	only Hg and Cd reach the gas combustion plant, 100 % of them are assumed to be emitted	partly in water and sludge, that means in soil and water as final recipients
Inorganic non-metals:	salinisation/ public water supply	behave very different; individual considerations must be made for each compound		
Chlorine		90 % is emitted with leachate, 10 % with the gas	-	passes unchanged
Sulphur		is reduced to sulphide; emitted to atmosphere as H_2S and water and partly precipitated	converted to SO_x	H_2S to atmosphere, Sulphate to the water, sulphide is precipitated
Nitrogen		reduced to NH_4^+, all N is emitted with water	-	NH_4^+; may be oxidised to NO_3^- and reduced to N_2 depending on the leachate treatment technology

Table 2.1: Waste components and their behaviour

Emissions, other pressures and impacts from landfills include:

- noise, dust from delivering vehicles
- litter, e.g. papers, plastics and other light materials
- odours
- vermin, rats, birds
- landuse
- fire and explosions
- disturbance of vegetation and landscape
- emissions to atmosphere by landfill gas (methane, carbondioxide)
- emissions of leachate to soil, groundwater and surface waters

Technical and operating measures can minimise dust, noise and litter, vermin and birds by, for instance, daily covering with soil, compaction, proper fencing etc. Fire and explosions can also be controlled through good operational practices. In terms of the potential release of dangerous substances into the environment, the most important routes are via emissions to the atmosphere caused by landfill gas and emissions to waters and soils caused by leachate.

Emissions of landfill gas and leachate can be either directly into the environment or via gas combustion plants or leachate treatment plants, as illustrated in Figure 2.2. The following sections summarise potential environmental risks associated with leachate and landfill gas.

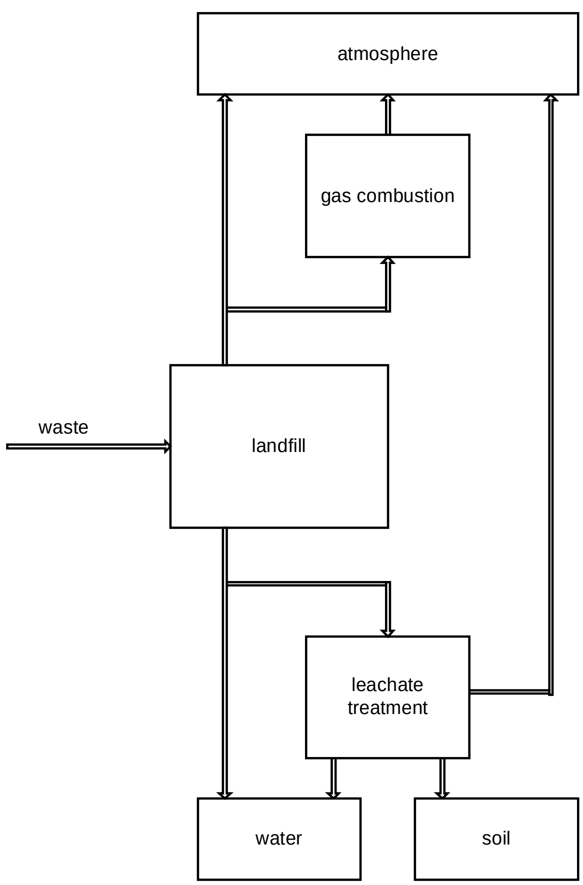

Figure 2.2: Transportation routes

2.1.1. Leachate

Leachate composition generally depends on the characteristics of the wastes deposited, rainfall conditions, landfill design, operation and age. Significant components may include heavy metals, chemicals and soluble organic substances such as the products of the decomposition of organic waste. Generally, the type and concentration of soluble organic substances vary with the age of the landfilled deposits and in general will decline over time. The concentration of heavy metals (Hg, Cr, Ni, Pb, Cd Cu, Zn) in leachates depends mainly on the acidity (pH value) of the leachate.

The conclusions of a major review into the composition of landfill leachate from landfills receiving mainly non-hazardous municipal waste in the UK and Ireland (United Kingdom Department of the Environment, 1995) were:

- Ammoniacal-N is the contaminant that, over extended time scales, has the greatest potential to adversely impact on surface and groundwater near landfills. Evidence indicates that many decades will pass before levels of ammoniacal-N fall to concentrations where direct release of leachate into watercourses will become a widespread option.
- A great deal of evidence has been compiled that demonstrates that heavy metals (specifically chromium, nickel, copper, zinc, cadmium, lead and mercury) are not generally present at significant concentrations in leachates from municipal landfills. Mean and median values for all metals were well below concentrations routinely determined in household sewage that is typically flushed from a domestic property.
- Red List substances were detected only in a few samples and at low concentrations. Exceptions included atrazine, simazine (which are ubiquitous in the aquatic environment), organotin, lindane and dichlorous, where further analytical studies were recommended. In spite of low level of Red List compounds measured to date, it is essential that following these analytical studies further work on levels, sources, fate and treatment of Red List substances in leachates is carried out.

Clearly, in relation to landfilling, the greatest environment risk to waters is associated with the uncontrolled disposal of wastes that contain dangerous substances, where these substances can be discharged either directly as a part of the leachate or where they undergo either a biological or physico-chemical transformation to other harmful substances that can be released via leachate into the aquatic environment. As many landfills throughout Europe do not currently conform to state of the art standards in relation to environmental protection, it must be assumed that groundwater and surface waters in the vicinity of many landfills in Europe is at risk of contamination from leachate. Where dangerous substances from deposited waste enter leachate and where no environmental controls exist for the collection and treatment of the leachate, groundwater and surface waters in the vicinity of a landfill are at risk of contamination from the dangerous substances.

2.1.2. Landfill gas

The biodegradation process in a landfill produces both leachate and landfill gas. The latter is primarily composed of methane and carbon dioxide as well as water vapour and is caused by the anaerobic decomposition of the filled material. Trace components provide landfill gas's characteristic vinegary smell. In certain circumstances, other gaseous compounds may be present in significant quantities, where large quantities of industrial waste of particular types have been accepted for disposal. For example, a very large proportion of plasterboard in a site may cause the evolution of hydrogen sulphide. The latter circumstance would be unusual and, normally, methane and carbon dioxide are the primary constituents of environmental importance in landfill gas.[1]

Methane is flammable and explosive at concentrations of 5-15 % v/v in air. The gas is usually saturated with moisture and is corrosive. If not properly monitored and controlled, landfill gas can give rise to flammability, toxicity, asphyxiation and other hazards as well as vegetation dieback. In addition to its explosive properties, landfill gas is also an asphyxiant when found in a closed space in significant quantities.

Landfill gas is produced in significant quantities in landfills, with a typical annual emission figure being about $10m^3$ of gas per tonne of deposited wastes. The rate of landfill gas production is a function of a number of factors including:

- the physical dimensions of the landfill site;
- the types of waste deposited and the associated input rate;
- the age of the waste;
- moisture content, pH, temperature and density of wastes deposited; and
- the application of cover, compaction and capping.

Leachate can also contain dissolved methane. As methane can emanate from solution, care should be taken to ensure that this does not occur either from an off-site leachate plume at sub-surface level or from leachate discharged to the sewerage network.

It should be appreciated that methane emissions will occur naturally from some soils and that other industrial activity, such as the proximity of gas mains, coal workings etc., may also cause gas production.

Landfill gas is a mixture which, under favourable conditions comprises up to 55 % by volume of methane, up to 45 % by volume of carbon dioxide and a host of trace substances. The percentage of trace substances is, in most cases, below 1 % by volume. In practice the methane content is frequently lower than 55 % since the gas is diluted with air as a result of gas collection and conveyance. Under normal conditions, a methane content of about 35 to 55 % by volume is to be expected (see Figure 2.3).

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[1] Irish Environmental Protection Agency (1997) Landfill Operational Practices. Environmental Protection Agency, Wexford, Ireland.

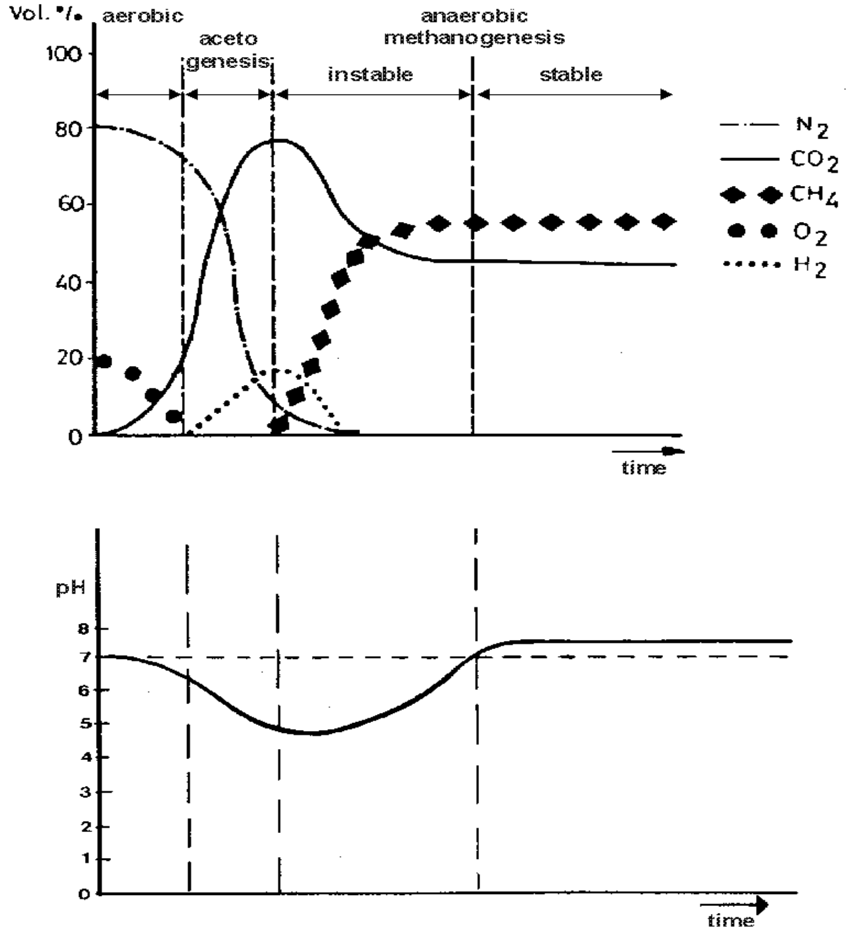

Figure 2.3: composition of landfill gas and pH value of leachate dependent on the landfill age

Trace substances

Landfill gas can contain trace substances (s. Table 2.2 to Table 2.4 and Figure 2.4), sometimes at concentrations that are of toxicological significance. Trace substances can be organic (e.g. chlorinated hydrocarbons) or inorganic (e.g. sulphur compounds). Household refuse and industrial waste contain a multitude of organic substances. Volatile substances with low water solubility migrate due to diffusion and pressure differences between the landfill and the atmosphere. Chemical and biological processes can also effect the conditions within the landfill (e.g. pH), reducing the solubility of specific substances. In addition, chemical or biochemical transformations can result in the creation of new substances which can be transported by landfill gas. Examples of this include:

- Tri- and perchlorethylene to vinylchloride
- amino acids to methyl- and ethylmercaptanes
- sulphur compounds to hydrogen disulphide.

In common with leachate, where dangerous substances enter a landfill as a component of a deposited waste, the possibility exists, depending on the characteristics of the substance concerned, that it might be released into the environment as part of the landfill gas. Where no gas collection and treatment exists, there is therefore no control over the discharge of gas from a landfill and the risk exists of uncontrolled release of dangerous or harmful substances into the atmosphere.

landfill	A mainly hazardous waste	B sanitary landfill
nitrogen	6,2 %	41,7 %
methane	64,9 %	33,2 %
carbon dioxide	28,9 %	25,0 %
(mg/m³)		
hydrogen sulphide	-	0,1
R 12	3,4	9,32
Chlorethan	5,8	-
R 114	3,6	17,8
R11	0,18	0,0048
Trichlorethan	0,018	0,013
Trichloethylen	0,032	0,028
Tetrachlorethylen	0,0406	-

Table 2.2: compounds in landfill gas from two closed sites , source: Franzius, Wolf, Brandt, Handbuch der Altlastensanierung, Verlag c.f. Müller.

Trichlorfluormethan	CCl_3F	1–84
Dichlordifluormethan	CCl_2F_2	4–119
Chlortrifluormethan	$CClF_3$	0–10
Dichlormethan	CH_2Cl_2	0–6
Trichlormethan	$CHCl_3$	0–2
Tetrachlormethan	CCl_4	0–0,6
1,1,1-Trichlorethan	$C_2H_3Cl_3$	0,5–4
Chlorethan	C_2H_3Cl	0–264
Dichlorethan	$C_2H_2Cl_2$	0–294
Trichlorethen	C_2HCl_3	0–182
Tetrachlorethen	C_2Cl_4	0,1–142
Chlorbenzol	C_6H_5Cl	0–0,2

Table 2.3: Chlorinated hydrocarbons in landfill gas (mg/m³) from several landfill sites referring to air free landfill gas

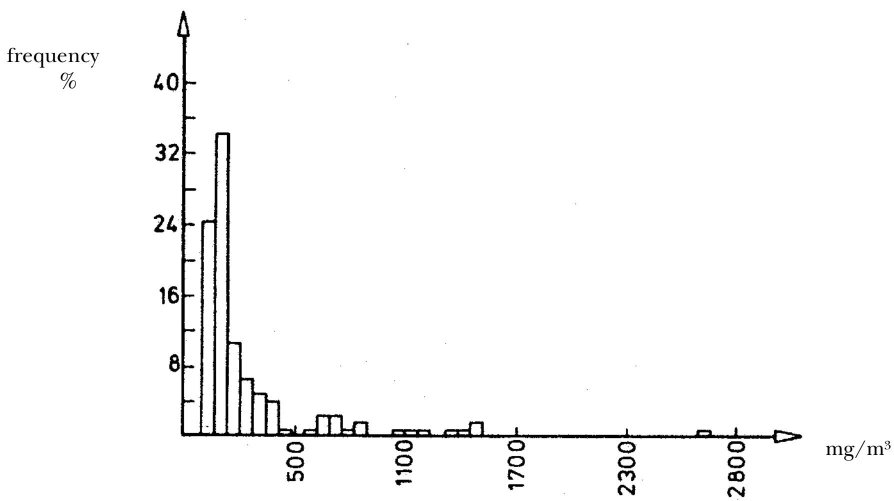

Figure 2.4: frequency of chlorine in landfill gas from several landfill sites, source s. Table 2.2

Ethan	C_2H_6	0,8–48
Ethen	C_2H_4	0,7–31
Propan	C_3H_8	0,04–10
Butan	C_4H_{10}	0,3–23
Buten	C_4H_8	1–21
Pentan	C_5H_{12}	0–12
2 Methylpentan	C_5H_{14}	0,02–1,5
3 Methylpentan	C_6H_{14}	0,02–1,5
Hexan	C_6H_{14}	3–18
Cyclohexan	C_6H_{12}	0,03–11
2 Methylhexan	C_6H_{16}	0,04–16
3 Methylhexan	C_6H_{20}	0,04–13
Cyclohexen	C_6H_{12}	2–6
Heptan	C_7H_{16}	3–8
2 Methylheptan	C_8H_{18}	0,05–2,5
3 Methylheptan	C_8H_{18}	0,05–2,5
Oktan	C_8H_{18}	0,05–75
Nonan	C_9H_{20}	0,05–400
Cumol	C_9H_{12}	0–32
Bicyclo (3,2,1) Oktan-2,3-Methyl-4-Methylen	$C_{10}H_{16}$	15–350
Dekan	$C_{10}H_{32}$	0,2–137
Bicyclo (3,1,0) Hexan-2,2-Methyl-5-Methylethyl	$C_{10}H_{13}$	12–153
Undekan	$C_{11}H_{24}$	7–48
Dodekan	$C_{12}H_{26}$	2–4
Tridekan	$C_{13}H_{28}$	0,2–1
Benzol	C_6H_6	0,03–7
Ethylenbenzol	C_8H_{10}	0,5–236
1,3,5-Methylbenzol	C_9H_{12}	10–25
Toluol	C_7H_8	0,2–615
m (p/Xylol	C_8H_{18}	0,376
o-Xylol	C_8H_{10}	0,2–7

Table 2.4: compounds in landfill gas (mg/m³) from several landfill sites referring to air free landfill gas
Source: Ehrig, H.-J, Sickerwasser aus Hausmülldeponien, Menge und Zusammensetzung, Müllhandbuch, Bd. 3, Erich Schmidt Verlag Berlin, 1982

2.2. Emissions from incineration

Incineration, as a treatment technology, results in the reduction of waste quantities and the destruction and detoxification, through oxidation, of certain hazardous components within the waste. However, incineration, and other thermal treatment technologies, is also a source of secondary waste such as fly ash and slags and results in the generation of emissions which, if improperly controlled, can lead to environmental risks. Therefore precautions have to be taken that dangerous substances contained in the original waste are not transferred to air, water or soil.

The incineration of municipal solid waste in 'waste-to-energy' facilities is a widespread and growing practice in some western European countries such as Germany, the United Kingdom, Denmark, Sweden and Switzerland, and also in Japan.[2]

The incineration process consists of a number of stages: drying (mainly at 50-200 °C), degasification (mainly at 250-400 °C), gasification (mainly at 400-600 °C) and combustion (mainly at > 600 °C). The final products of incineration depend to a large extent on the composition of waste incinerated (the feed) and the technical

[2] World Resource Foundation, Heath House, High Street, Tonbridge, Kent TN9 1DH, England. PRISM - Tech Brief (Ash) (1997), modified: April, 1998.

standards applying both to the incineration process and pollution abatement equipment. For instance, too much water in the feed can require too much energy for evaporation, and the waste will not burn-out completely. Chlorinated organic compounds must be controlled since chlorine will form hydrochloric acid (HCl) causing corrosion problems and also because chlorine can contribute to the formation of dioxin which can be released to the environment. Other important feed characteristics to be considered include:[3]

- ash content
- heating value or heat of combustion
- sulphur content
- phosphorus content
- nitrogen content
- physical state (solid, liquid, or gas)
- melting point
- boiling point
- particle size distribution of solids
- packaging (drums, pails, bulk)
- metals content

Pre-treatment of the feed is important:
1. to minimise the residue amount. Special fractions such as plastics, fine refuse, ferrous and non-ferrous metals, can be separated, e.g. through crushing and homogenisation with separators for ferrous and non-ferrous metals.
2. for pollutant extraction. Separation of leather residues (heavy metal extraction) and problematic substances such as mercury-batteries, nickel/cadmium-batteries or electronic scrap will reduce the toxicity of emissions arising from the process by eliminating dangerous substances from the feed.

2.2.1. Emissions to air

Emissions to air from incineration of waste can be grouped under a number of headings:
- organic compounds such as hydrocarbons, dioxins and furans, soot and volatile organic carbons
- heavy metals
- inorganic gases such as NOx, SO_2 and HCl
- climate-relevant gases
- dust

A brief description of these potential emissions is provided below.

Organic compounds
Incineration can result in the production and release of a large variety of organic compounds. Very important in this regard, is the possible production and release of dioxins and furanes which are known to be highly toxic. A 1994 US-EPA risk assessment of dioxin confirmed earlier reports of 1985 and 1988 that dioxins are potentially carcinogenic. The immune system also can be directly and indirectly damaged by dioxins, even in small doses. Dioxins and furanes are highly liposoluble compounds being both environmentally persistent (i.e., difficult to degrade) and bioaccumulative.

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[3] Thomas E. Higgins: Pollution Prevention Handbook. 1995 by CRC Press, Inc.

Dioxins and furans can arise from dioxins and furans already present in the incinerated waste which escaped due to insufficient incineration temperatures. They can also be formed in the gas phase at temperatures of 500 to 700°C due to the coalescing of organic molecules and chlorine donors such as chloride salts, PVC, HCl or other chlorinated molecules, as well as by a variety of solid phase reactions at temperatures below 500°C on particles flowing through the incinerator. A good understanding of how dioxins and furans are formed together with the application of appropriate operating conditions can minimise their production.[4]

Thermal waste treatment processes can also lead to the generation and release of a number of highly toxic and carcinogenic organic compounds such as benzene, phenols, polyaromatic hydrocarbons (PAHs), benzo(a)pyrene, chlorinated organic compounds and soot. In practice, the suite of organic compounds that may be released are monitored by measuring the total organic carbon content of the emission.

Heavy metals

Heavy metals can be grouped into various classes, each with its specific issues. Metals such as Cd, Cr, Hg and Pb are highly toxic. Cu, Pt and Ni tend to be less toxic but they are potent catalysts and contribute to a complex organic chemistry in the flue gases of combustion plants. In particular, they can contribute to the post-formation of dioxins in the flue gases. The volatility of heavy metals is influenced by the conditions of incineration and they may tend to escape through the smoke stack. In order to avoid adverse effects on human health and the environment, the best option, other than removal from the feedstock, is to decrease their bioavailability by ensuring that they are in a form that is neither breathable nor leachable.[5]
Incineration of solid waste contributes significantly to the overall global emission of heavy metals, as illustrated in Table 2.5:

Metal	Atmosphere emissions from waste incineration	
	1000 tonnes / year	As % of total emissions
Antimony	0.67	19.0
Arsenic	0.31	3.0
Cadmium	0.75	9.0
Chromium	0.84	2.0
Copper	1.58	4.0
Lead	2.37	20.7
Manganese	8.26	21.0
Mercury	1.16	32.0
Nickel	0.35	0.6
Selenium	0.11	11.0
Tin	0.81	15.0
Vanadium	1.15	1.0
Zinc	5.90	4.0

Table 2.5: World-wide atmospheric emissions of trace metals from waste incineration[6]

[4] Laurent Bontoux, European Commission - Joint Research Centre. Institute for Prospective Technological Studies. The Incineration of Waste in Europe: Issues and Perspectives

[5] Laurent Bontoux, European Commission - Joint Research Centre. Institute for Prospective Technological Studies. The Incineration of Waste in Europe: Issues and Perspectives

[6] D. Stanners, P. Bourdeau: Europe's Environment. The Dobris Assessment. European Environment Agency, Copenhagen, 1995.

A special problem is the separation of mercury. Because of the high vapour pressure of elemental mercury, there is almost no binding of mercury in slags or filter dust. Almost 100 % of elemental mercury present in the waste is therefore emitted.[7]

Climate-relevant gases

Due to the risk of climate change from the release of anthropogenic substances, in particular CO_2, the emissions of climate-relevant gases from incineration have to be kept as small as possible.

Waste from human settlements contains on an average about 25 % by weight carbon, which is released in thermal treatment as carbon dioxide (in the order of 1 t CO_2 per t waste). [8] Other climate-relevant gases produced through incineration of waste include carbon monoxide, nitrogen oxides, sulphur oxides, chlorhydric acid, fluorinehydric acid and organic hydrocarbons.

Dust

Very fine mineral dust can cause respiratory problems and should therefore be captured and fixed.

Inorganic gases

Acidic gases such as sulphur dioxide and hydrochloric acid are a major problem for air pollution. In contrast to many other substances the short-term impact has a high significance, for instance, in forming smog in cities.

2.2.2. Emissions to water

Emissions to water arise from several locations in the incineration process including:

- Wastewater from wet exhaust gas cleaning
- Wastewater from the wet slag removal equipment

Wastewater from wet exhaust gas cleaning

The quantitatively and toxicological most significant heavy metals in these washwaters are lead, cadmium, copper, mercury and zinc. Antimony similar to arsenic in its chemical and toxic behaviour, can be released in concentrations of 0,1 -3 mg/l[9].

Wastewater from the wet slag removal equipment

The quench water contains salts and unburned organic material from the residue. It contains particles in suspension and is alkaline. Water from waste water treatment has a high concentration of neutral salts which are released to surface water.

2.2.3. Emissions to land and soil

Slags and ashes

Slags and ashes from waste combustion have generally the same pollutants as air emissions, but in different concentrations and composition.

Metals are present in the solid residue fractions, for example: antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel, tin and zinc[10], see Table 2.6

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[7] J. Wirling, H. Schroth: Quecksilberabscheidung aus Abgasen einer Klärschlammverbrennungsanlage an Braunkohlenkoks. In: Müll und Abfall 10, 1996.

[8] K. Wiemer, R. Frohne, U. Täuber, M. Kern: Kohlenstoff als Ressource - Mechanisch-Biologische Abfallaufbereitung mit dem Ziel der sofortigen oder späteren thermischen Nutzung. Müll und Abfall **27** (1995) 6, p 403-415 and **27** (1995) 11, p 769-777.

[9] ATV Schriftenreihe, Rückstände aus thermischen Abfallbehandlungsanlagen, Feb. 1998, Hennef, p 107

[10] World Resource Foundation, Heath House, High Street, Tonbridge, Kent TN9 1DH, England. PRISM - Tech Brief (Ash) (1997), modified: April, 1998.

	Elements
	in % by weight
SiO_2	45 – 60
Al_2O_3	5 – 10
Ca-compounds	5 – 10
Fe_2O_3	3 – 15
MgO	1 – 5
Na	1 – 5
K	0 – 2
SO_3	1 – 5
Cl	0.1 – 1
F	0 - 0.1
C	0.5 – 5

Table 2.6: Main composition of grate ashes from municipal solid waste incineration[11]

The pH of the leaching fluid is one of the most important factors affecting the mobility of metals. Most heavy metals will leach under acidic conditions; some metals such as lead, zinc and aluminium can also leach under very alkaline conditions.

Information about the contents of organic compounds in slags is scarce, apart from the highly toxic dioxins and furanes.[12] Dioxins and furanes are apparently present in all municipal solid waste incinerator ash residues. They are strongly absorbed by or otherwise fixed to the solid surface of ash residue and therefore to be highly insoluble in water. Therefore, it is unlikely that they will leach to a significant extent from a landfill and contaminate groundwater. Co-disposal with large amounts of organic solvents that may mobilise dioxins and furanes should be avoided. Concentrations of dioxins and furanes in leachate collected from ash residue mono-landfills have characteristically been reported to range from non-detectable to parts per quadrillion (ppq) levels, i.e. at levels that are presently considered to be below regulatory concern.

Filter dust

The disposal of filter dust/fly ash from waste incineration plants is a serious problem. Dust contains in concentrated form heavy metals, soluble salts (chlorides, sulphates), organic compounds (e.g. polycyclic aromatic hydrocarbons or soot), including chlorinated hydrocarbons, which have potentially toxic and in particular carconogenic properties. In comparison to the other residues from incineration, this fraction contains the highest concentration of chlorine containing organic pollutants.

Two distinct trends regarding metal distribution as a function of particle size have been found in fly ashes: a parabolic distribution having a maximum in central fractions for less volatile metals (Cr, Cu), and a sigmoidal distribution that favours high concentrations of more volatile metals (Cd, Pb, Zn) in the smallest fractions [13].

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[11] T. Leclaire: Behandlung und Verwertung von HMV-Rückständen. Gerhard-Mercator-Universität - GH Duisburg. Letzte Änderung: April 1998.

[12] T. Priester, R. Köster, S. Eberle: Charakterisierung kohlenstoffhaltiger Bestandteile in Hausmüllverbrennungsschlacken unter besonderer Berücksichtigung organischer Stoffe. In: Müll und Abfall, 6, 1996.

[13] N. Alba, S. Gassó, T. Lacorte and J.M. Baldasanto: Characterization of Municipal Solid Waste Incineration Residues from Facilities with Different Air Pollution Control Systems; in: Journal of the Air & Waste Management Association, Volume 46, November 1997, pp 1170-1179.

In fly ash residue and scrubber residues, the concentrations of dioxins and furanes characteristically range from parts per trillion (ppt) to parts per billion (ppb). In bottom ash residue, concentrations are characteristically at ppt levels.[14]

Residues from air pollution control devices tend to have high salt concentrations. Salts are difficult to be removed from the waste stream. Inorganic salts (more properly anions and cations of inorganic salts) such as Na, K, Ca, NH_4, Cl, SO_3, S, and Br have been found in leachates from municipal solid waste incinerator ash residues . Many of these salts are highly soluble in water[15], so that these residues require proper management.

Most of the heavy metals are attached to particles and with effective dust extraction, they accumulate in the filter dust. Special attention is required for management of potentially toxic heavy metals.

Loaded adsorbents

Adsorbents are loaded with HCl, HF and SO_2, heavy metals (mercury) and organic pollutants (dioxins/furanes).

Catalytic converters

There is only minimal loading with heavy metals, because the catalytic converters are installed after dust removal and the other pollutants separation.

[14] World Resource Foundation, Heath House, High Street, Tonbridge, Kent TN9 1DH, England. PRISM - Tech Brief (Ash) (1997), modified: April, 1998.

[15] World Resource Foundation, Heath House, High Street, Tonbridge, Kent TN9 1DH, England. PRISM - Tech Brief (Ash) (1997), modified: April, 1998.

3. Evaluation of dangerous substances

In this chapter a methodology is presented for evaluating dangerous substances in waste streams treated by both landfilling and incineration. Based on this evaluation a waste treatment technology and a relevant waste stream will be selected for further investigation at a later stage. This evaluation and selection will be done as far as possible by scientific methods. However, the data available at both national and European level are too weak to base decisions on scientific methods alone and this analysis was additionally based on the experience of relevant experts and of representatives from national authorities.

Once a waste stream and technology has been selected, the next step will be to identify measures to reduce environmental impacts resulting from its management. Measures will be identified along the whole waste chain from the point at which the waste is generated to the point at which it is finally disposed of.

3.1. Evaluation methods

Life-cycle-assessment (LCA) of products is considered as one of the most comprehensive approaches for the evaluation of environmental impact. While life-cycle assessment is not directly applicable to the analysis of waste treatment methods such as landfilling and incineration, since it is primarily designed to conduct 'cradle to grave' analysis of products, the general approach adopted in LCA, namely the measurement and comparison of environmental impacts of substances is useful in the context of the current analysis and will be used here.

3.1.1. Overall approach

LCA consists of four steps as illustrated in Figure 3.1:

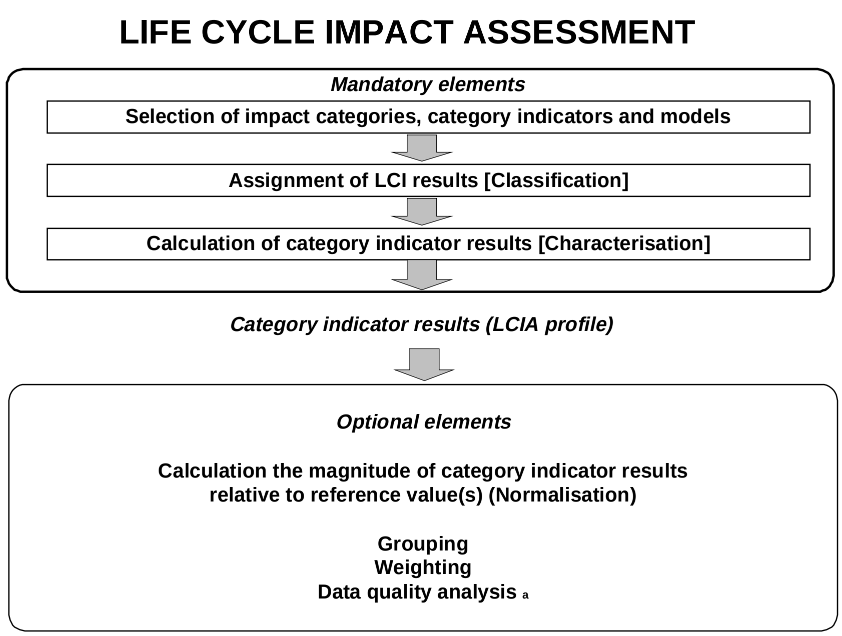

Figure 3.1: Steps of life cycle assessment

The first step is the selection of impact categories such as global climate change, ozone depletion and eutrophication. Six categories are defined in the draft ISO 14042 (see table 3.1). For each category, a representative indicator is chosen. Other substances that contribute to the impact category are weighted by a so called **equivalence factor** according to their relevance for the specific category in relation to this indicator. For example, CO_2 is the indicator for the category 'global warming', CH_4 contributes 21 times more[16] to the global warming potential, thus the mass of CH_4 calculated in the inventory analysis is multiplied 21 times to consider its contribution to this category. This weighting is quite feasible for categories like global warming or acidification, but for a category such as human toxicity there is no national or international agreement on how to consider the relevance of the different substances properly.

The second step is the assignment of inventory data (in this case, information on emissions from landfilling and incineration) to the selected categories.

The third step is the aggregation of inventory data for each category which provides an environmental profile, based on the impact categories. Aggregation means to multiply the quantities of each parameter with their equivalence factor and to sum up the results for every category.

The fourth step is the interpretation of the aggregated results. This step is optional and difficult, because there is no scientific basic to answer questions such as whether ozone depletion is worse than global warming. At the moment there are no such methods agreed on national or international level. For this reason, different methods, like normalisation or weighting the impact category results are applied to carry out the interpretation.

Comprehensive and reliable data on the release of dangerous substances from waste disposal facilities on European level is still lacking. Only data on air emissions from landfill and incineration facilitates are provided by CORINAIR for 1990, which are not sufficient for the implementation of steps 3 and 4 of LCA. Therefore this evaluation of dangerous substances is mainly limited to steps 1 and 2 (qualitative analysis).

3.1.2. Impact categories and indicators

The SETAC (Society of Environmental Toxicology and Chemistry) and institutions for standardisation (ISO, DIN) have agreed on 10 categories to be used to evaluate environmental impacts[17]. These are listed in Table 3.1 below.

	Category	Foot-note	Indicators for the category	Remarks
1	Global climate change	1	CO_2, CH_4, N_2O, CCl_3F	Increasing levels of gas that can lead to a rise in temperature (greenhouse effect)
2	Ozone depletion	2	CCl_3F, CCl_2F_2, halons	Increasing level of gas causing a depletion of the stratospheric ozone layer
3	Photochemical oxidant formation (smog)	1	NO_x, CH_4, Ethene, CCl_4	Increasing level of substances that lead to the formation of (summer)smog that affects health of humans and plants.
4	Eutrophication	1	PO^{3-}, NO_x (air), total nitrogen (water)	Increasing level of substances that lead to a loss of dissolved oxygen in aquatic systems
5	Acidification	1	SO_2, NO_x, HCl, HF	Emission of substances that acidify the environment

[16] International Panel of Climate Change IPCC; 1996

[17] SETAC (Society of Environmental Toxicology and Chemistry): Guidelines for Life-Cycle-Assessment: A Code of Practice, Workshop held in Sesimbra, Portugal 31. March - 3. April 1993

	Category	Foot-note	Indicators for the category	Remarks
6	Depletion of resources	1	Energy resources (oil, gas, coal)	Exhausting of resources by human activities. This can be divided into biotic (renewable) and abiotic resources
7	Land use, degradation of landscape	2	Land use in m^2	This category comprises the area itself that is used for e.g. landfills and the degradation of landscape that can affect ecosystems
8	Human toxicity (manly cancer risk considered)	1	As, Cd, Cr(VI), Ni, PCB, Dioxin, Benz(a)pyrene	The issue for this category is human health. This category is not defined yet. It considers substances that cause cancer, affect the reproduction etc.
9	Ecological toxicity	3	Hydrocarbons, Cl-, AOX[18], ammonium, Nox, HS, HF	Emissions that affect ecosystems
10	Nuisance to man, plants and animals (odour, noise, light...)	2	not specified	This category is mainly related to noise and is applied especially to human activities close to urban settlements

1 Issues from ISO/CD 14042 2-2, 1997
2 DIN/NAGUS Working Group AA3/UA2
3 German Environment Agency (Umweltbundesamt)[19]

Table 3.1: Impact categories

The majority of the categories defined by ISO have global character. Public awareness and issues arising relating to waste disposal and treatment facilities tend to have a more local/regional character. The negative reaction of the public to waste issues is often caused by factors such as bad smells, noise, traffic problems and landfill gas emissions. To account for these local/regional concerns, it seems appropriate that categories 3 and 10 which represent the local problems, are included in the analysis.

3.1.3. Method used in this study

As stated above the LCA method can not be applied in total for the purposes of this study. LCA is normally used to compare the ecological performance of products or processes and considers the whole life-cycle of the products.

The impact categories and the related indicators will be used to group and to sort dangerous substances (see Table 3.1). For the evaluation of dangerous substances emitted by disposal processes their environmental relevance will be considered (see Table 3.2).

	Category	Environmental Relevance	Remarks
1	Global climate change	very high relevance	
2	Ozone depletion		not considered in the study
3	Photochemical oxidant formation	high relevance	
4	Eutrophication	middle relevance	
5	Acidification	middle relevance	
6	Depletion of resources	high relevance	for oil, gas and coal
7	Land use, degradation of landscape		not considered in the study
8	Human toxicity	very high relevance high relevance	cancerogenic substances dust and particles

[18] AOX: adsorbable organic halogen compounds

[19] Ökobilanz für Getränkeverpackungen UBA Texte 95/52, German Environment Agency (Umweltbundesamt), 1995

	Category	Environmental Relevance	Remarks
9	Ecological toxicity		
10	Nuisance to man, plants and animals (Odour, noise, light...)	middle relevance	

Table 3.2: The relative relevance of impact categories [20]

Emission data on European level is considered. If no data on European level is available data on national level were used.

Based on this, the amount and the environmental relevance will be taken into account to evaluate the environmental relevance of dangerous substances.

3.2. Environmental impacts from waste treatment

3.2.1. Allocation of waste to treatment/disposal systems

Table 3.3 provides a summary of disposal routes for wastes in a number of European countries and regions. This illustrates that landfilling remains the predominant disposal route for wastes while there is a growing trend towards increased incineration.

Geographical coverage	Year	Waste generation 1000 t	Land-filling	%	Incine-ration	%	Recycling	%	Other treatment	%
Denmark	1996	12912	2524	20	2507	19	7787	60	94	1
Germany	1993	338500	253900	75		84600		25		0
Ireland	1995	6888	5013	73	46	1	933	14	896	13
Netherlands	1996	50960	8655	17	5265	10	37040	73		0
Sweden	1990	13105	9863	75	1646	13	1258	10		0
Spain (Catalonia)	1995	6519	3621	56	664	10	2233	34		0

Table 3.3: Total waste generation by treatment method in selected EU countries and regions

In future, it is likely that incineration of waste will increase due to national and EU legislation which sets limits on the organic content of waste destined for landfilling. Reductions in the landfilling of organic waste should also lead to reductions in methane and trace organic substance emissions. However, landfill will remain an important part of an integrated waste management system because non-recoverable components such as the residues of incineration will probably continue to be landfilled.

Besides landfilling and incineration an increasing amount of waste is recycled in production facilities. Inorganic waste is used as construction material. Organic waste is co-incinerated in blast furnaces and cement kilns. This may lead to a relaxation of the waste situation with more facilities to treat waste available in future. However, it is essential that the same level of regulatory control exists for this type of treatment as for conventional waste treatment methods.

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[20] The environmental relevance is presented in a study [19] of the German Environment Agency (Umweltbundesamt). Global climate change and human toxicity were evaluated as very important; global climate change because of its global relevance and human toxicity because of the poosible direct effect to human health. For the estimation of the relevance of the other categories also country specific aspects are considered.

3.2.2. Description and evaluation of the major environmental impacts from landfill

As set out in Chapter 2 of this report, there are two major pathways by which dangerous substances can be transported into the environment from landfill: evaporating gases and leachate.

Major emissions to atmosphere from landfill are summarised in Table 3.4 together with the environmental category most relevant to the emission.

Compound	Composition of Gas	Environmental Category
CH_4	35-55 %	Global climate change, inflammable, explosive
CO_2	40-45 %	Global climate change
Nitrogen	5 %	No impact
Chlorinated organic	1-5 %	Human toxicity
Fluorinated organic	1 %	Ozone depletion
Organic trace substances	<1 %	Human toxicity, nuisance
Volatile metals Hg, Cd	<1 %	Human toxicity, .

Table 3.4: Air Emissions from landfill

The most significant contribution of landfill gas emissions at global level is the generation of CH_4 and CO_2. According to the CORINAIR Guidebook, landfills are responsible for about 18 % to the total CH_4 emissions. However, trace substances can be significant at local level, affecting both employees on landfills and adjacent communities. These substances should therefore be assigned to the categories human toxicity and nuisance (mostly odour).

Major emissions to surface and groundwater from leachate are summarised in Table 3.5 together with the environmental category most relevant to the emission.

Compound/Parameter	Environmental category
Cd, Ni	Human toxicity (cancer)
Cu, Zn, Pb, Hg	Ecological toxicity (surface-/groundwater)
Salts, Chlorine, Sulphide	Ecological toxicity (surface-/groundwater)
Nitrogen	Eutrophication
COD	Eutrophication

Table 3.5: Leachates from landfill

For the estimation of the relevance of these emissions, a comparison of municipal waste water and landfill leachate after treatment is useful:

Parameter	Municipal Waste Water after water treatment (t/a)	Municipal waste landfill: Leachate after water treatment (t/a)	Percentage %
Hydraulic load	$8883*10^6 (m^3/a)$	$9*10^6 (m^3/a)$	0,1
COD	533000	1080	0,2
AOX	440	3,15	0,72
Cd	8,9	0,027	0,30
Ni	360	0,90	0,25
Zn	890	1,80	0,2
NH_4	8880	9	0,10
Total N	107000	630	0,59
Total P	8880	9	0,10
Chloride	888000	18000	2,03
Sulphate	977000	720	0,07

Table 3.6: Total loads from Waste Water Treatment in Germany [21]

[21] Sickerwasser aus Siedlungsabfalldeponien, ATV Arbeitsberichte,Korrespodenz Abwasser 3/93, S 397 fff,1993

This table shows that when leachate emissions from landfills subject to treatment, are compared with discharges from municipal waste water treatment, chloride is the most significant emission in quantitative terms. However, these figures assume that waste water treatment units are installed at landfills, which is not usually the case. Therefore there is a potential risk for the emission of dangerous substances into groundwater and surface waters. For this reason, heavy metal emissions and nitrogen emissions are kept in the evaluation list.

Evaluation of dangerous substances for landfill

In Table 3.7 the most important dangerous substances emitted from landfills are listed.

Dangerous Substances	Path	Category	
CH_4	Gas	Global climate change	High contribution of landfills to overall emission
Salt, e.g. Chloride	Leachate	Ecological toxicity	important, high contribution from landfill waste water treatment
Total N, NH_4	Leachate	Eutrophication	important because of the local contamination of surface and groundwater
Organic Emissions	Gas	Human toxicity, nuisance	important for employees and local communities
Heavy Metals Cd, Ni, Cu, Zn Pb, Hg	Leachate	Human toxicity	less important because little contribution to total emissions, assumed to be generally stable in the landfill body

Table 3.7: Dangerous substances from landfill

Conclusions

The problems related to the emission of gases are mainly caused by organic substances in waste which result from biological degradation of organic materials. The Landfill Directive, when implemented, will result in a reduction in organic inputs to landfills so this problem is likely to decrease in the coming years.

Although leachate from landfills has potentially high concentrations of heavy metals, organic substances and salts, most of the potential problems associated with this can be solved by appropriate waste water treatment prior to discharge. Only salts, e.g. chlorides, pass the treatment facility without any reduction of concentration. Compared to the loads released after municipal waste water treatment, landfill leachate contributes less than 1 % for most components, with the exception of chloride.
Problems associated with landfilling can be controlled by good operational practices, by exercising tight control over the type of wastes accepted into the landfill and by proper treatment and management of emissions to atmosphere and water.

3.2.3. Description and evaluation of the major environmental impacts from incineration

As described in Chapter 2, there are four major pathways by which dangerous substances may be transported to the environment from incineration; air emissions, slags, fly ashes and residues from gas cleaning.

The slags from incineration contain dangerous substances which generally are not in soluble form. These slags can be recycled, e.g. for road construction.

Air emissions

Waste incineration is one of the important sources of dioxin and hydrochloric acid[22] emissions into the air. Nriagu and Pacyna[23] also indicated that waste incineration contributes strongly to the total emissions of heavy metals. The most important metal emissions are mercury, lead, antimony, tin, cadmium, copper, zinc and arsenic. Volatile metals such as mercury, cadmium and lead can be transported over long distances.

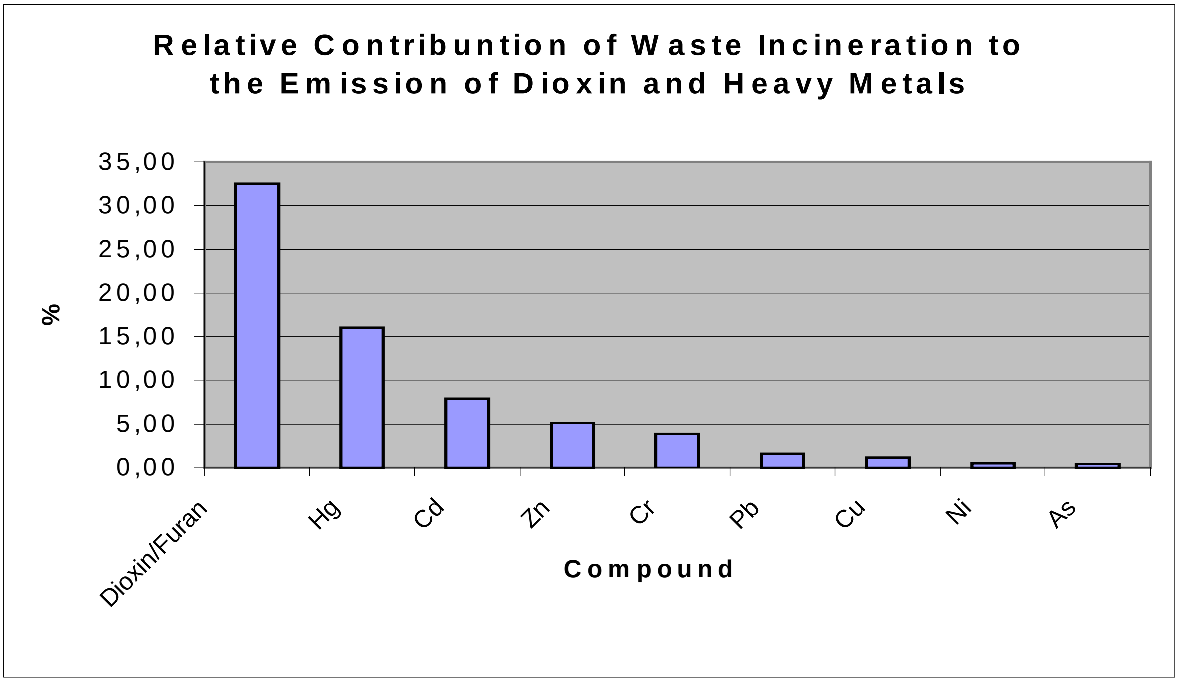

Figure 3.2: Rel. contribution of waste incineration to total emissions (according to SNAP code, Industry, traffic, agriculture) in EU 15 in 1990; source: The European Atmospheric Emission Inventory of Heavy Metals and Persistent Organic Pollutants for 1990, Umweltbundesamt, Berlin

The emission of dioxins, furans and heavy metals can be reduced by efficient abatement technologies. However, the ISWA report[24] states that the technological standard of incineration plants in Europe varies significantly from one country to another. As standards improve, total emissions from incineration are likely to be reduced in future. However, this might be offset by increased incineration capacity. Reliable data about total emissions and emission sources are not available at European level.

Fly ashes and residues from gas cleaning

With incineration temperatures above 800 °C, a high percentage of metals will be gasified. Thus, metals are transferred to the gas phase and partly condense before entering the gas cleaning unit. The condensed metals are mostly adsorbed on the surface of small fly ash particles. The fly ash tends to concentrate metals. The remaining vaporised metals are transported to the gas cleaning unit and washed out.

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[22] VROM 1991, Essential Environmental Information: The Netherlands, Ministry of Housing, Physical Planning and Environment; The Hague

[23] Nriagu, J.O and Pacyna, J.M., 1988 Quantitative assessment of world wide contanination of air,water and soil with trace metals; Nature 333, 134-139

[24] ISWA Report, Energy from waste, 1995, Denmark

	Contents mg/kg		
Substances	Slags	Fly Ash	Residues from Gas Cleaning
Cd	<0,5 - 10	50-1000	300-500
Tl	< 2	0-50	0-2
Hg	<0,05-5	2-30	10-30
As	0,5-50	10-100	40-100
Co	15-35	30-100	5-20
Cr	50-1000	50-2000	50-200
Cu	500-1500	300-5000	500-1500
Ni	25-100	100-400	30-100
Pb	100-3500	1000-12000	4000-10000
Sb	20-200	300-1000	300-1000
Sn	100-250	500-3000	-
Zn	500-2500	5000-40000	20000-30000

Table 3.8: MSW-Incineration, heavy metal concentration[25] (MSW: municipal solid waste)

Organic substances are partly destroyed during incineration, but new toxic substances can be formed. Dioxins and furanes are the most important dangerous organic substances. Other organic substances like PCB and PAH may also be released. These organic compounds are also preferably adsorbed by the fly ash and washed out in the gas cleaning unit. Thus the concentration of organic compounds in the fly ash and the residues are significantly higher than in the slags, as illustrated in Table 3.9.

Substances	Slags	Fly Ash	Residues from Gas Cleaning
PCDD/F	4-25 ngTE/kg	100-10000 ngTE/kg	100-10000 ngTE/kg

Table 3.9: MSW-Incineration, typical dioxin and furan concentrations [26] (MSW: municipal solid waste)

Quenching and gas scrubbing processes produce high amounts of waste water containing metals. These waste waters are subject to physical/chemical treatment to reduce the metal concentration. This treatment results in high salt concentrations (e.g. NaCl) in the treated effluents that are released to surface water.

Evaluation of dangerous substances from incineration

In Table 3.10 the most important substances emitted from incineration units are listed.

Dangerous substances	Path	Category	Remark
Organic Compounds especially PCDD/F	Gas, fly ash, residues	Human toxicity . Ecological toxicity	very important, incineration is a major contributor
Volatile Heavy Metals Hg, Cd, Pb	Gas, fly ash, residues	Human toxicity .	important because of transboundary movement
HCl	Gas	Acidification	important
Metals As, Cd	Gas, fly ash, residues	Human toxicity .	important, carcinogenicity
Salt, e.g. chloride	Waste water, fly ash, residues	Ecological toxicity	important, high soluble transport to surface water

Table 3.10: Dangerous substances from landfill

[25] T. Leclaire: Behandlung und Verwertung von HMV-Rückständen, Gerhard Mercator-Universitat-GH Duisburg; 1998

[26] T. Leclaire: Behandlung und Verwertung von HMV-Rückständen, Gerhard Mercator-Universitat-GH Duisburg; 1998

Conclusions

In general, incineration of waste is a small contributor to the major environmental issues such as global warming or ozone depletion. Other human activities such as power generation, industrial combustion or emissions from traffic are more important in overall terms. However, there are four important problems caused by incineration:

- incineration is one of the key generating sources for the emission of organic micro-pollutants such as dioxins and furans;
- incineration is an important source for the release of volatile metals such as mercury, cadmium and lead which can be transported over long distances;
- trace metals especially heavy metals are not destroyed during incineration. The minor part remains in the slags and can be made inert. The major part is transferred to the fly ashes and the residues from gas cleaning and stays soluble. Thus, fly ashes and residues cannot be landfilled without pre-treatment;
- in common with landfill, high neutral salt loads are released from waste water treatment. In contrast to landfilling only surface water is affected by this release.

3.3. Ranking of dangerous substances for landfill and incineration

Table 3.11 presents the overall conclusions in relation to the emissions from landfill and incineration. This 'ranking' of dangerous substances has been elaborated after thorough literature and internet searches and consultations with the scientific community and representatives from local, regional and national authorities, so that the relative importance of each substance could be based on the experience of relevant experts. As said at the beginning of this chapter a pure scientific method for the evaluation of the hazardous potential of these substances does not exist and the application of LCA is lacking a solid data base.

There are three types of emissions that are of relevance at global level, namely:

- organic micro pollutants, particularly dioxins and furans (incineration is still a major generating source);
- greenhouse gases, particularly methane (landfilling is one of the most important sources as stated in the EMEP/CORINAIR Atmospheric Emission Inventory Guidebook and
- volatile heavy metals (incineration is still a major generating source for specific metals).

Emissions of these substances contribute to slow but continuous degradation of environmental conditions.

Other emissions from incineration such as PCB have a more regional character and are important at regional/local level.

Landfill emissions other than methane are mainly of local or regional importance. Most of these emissions are emitted in a diffuse manner to the surrounding environment and, in particular, to groundwater. In regions where communities rely on groundwater for public water supply, such emissions, if uncontrolled, can have implications for public health. As stated above (Chapter 0), organic trace substances produced as a result of biodegradation processes can also be a source of nuisance to local communities as well as being a potential risk to human health. For both landfill and incineration, discharge of waste waters results in relatively high emissions of chloride salts.

Dangerous Substances	Source	Category	Remark
Organic Compounds especially PCDD/F	Incineration	Human toxicity Ecological toxicity .	very important, incineration is a major contributor
CH_4	Landfill	GWP	very important
Volatile heavy metals Hg, Cd, Pb	Incineration	Human toxicity Ecological toxicity	very important because of transboundary movement
Total N, NH_4	Landfill	Eutrophication	important because of the local contamination of surface and groundwater
HCl	Incineration	Acidification	important
Heavy metals As, Cd	Incineration	Human toxicity	important, carcinogenicity
Salt, e.g. chloride	Landfill and Incineration	Ecological toxicity	important, high loads to surface and groundwater
Organic emissions	Landfill	Human toxicity nuisance	important for employees and neighbourhood
Heavy metals Cd, Ni, Cu, Zn Pb, Hg	Landfill	Ecological toxicity Human toxicity	less important because little contribution to total emissions, assumed to be stable in the landfill body

Table 3.11: Ranking of dangerous substances from landfill and incineration

3.4. Selection of a relevant waste stream

The emissions listed in Table 3.11 either derive directly from treated wastes or are formed following transformations that occur during the treatment process, either in a incinerator or in a landfill. They are generally formed through the treatment or disposal of mixed waste streams such as municipal waste. For further study, a waste stream has to be chosen containing substances likely to give rise to these emissions. This waste stream should also be of relevance in a European context. In relation to this, it is interesting to note the results of a survey carried out by OECD where 10 European countries were asked. about their present and future waste minimisation problems and priorities[27]. The following results were obtained (Table 3.12):

Country	Key Waste Stream	
	present	future
Austria	Waste oil, lubricants, photochemical	WEEE, waste medicines, end-of-life vehicles
Denmark	no information	no information
Finland	sewage sludge	WEEE, end-of-life vehicles
France	waste oils, end-of-life vehicles	waste oils, end-of-life vehicles, PCB, WEEE, medical waste
Germany	Paint sludges, WEEE, sewage sludge	WEEE, end-of-life vehicles, sewage sludge
Italy	no information	no information
Netherlands	Waste oil, dredging spoil, CD waste, phosphorgypsum	dredging spoil, phosphorgypsum
Norway	Hazardous waste in general	WEEE, Scrapped oil installations
Switzerland	Packing, beverage containers, metalplating sludges	Packing, beverage containers, metalplating sludges
UK	WEEE, end-of life-vehicles, waste oil	Clinical waste, PCB
WEEE: waste from electrical and electronic equipment		

Table 3.12: Present and future key waste streams in selected European Countries, OECD 1998

[27] OECD Group on Pollution Prevention and Control, Waste Minimisation Profiles of OECD Member Countries; 1998, Paris

Most of these waste types listed above contribute to the emission of dangerous substances identified in this report. The list also mentions the various streams identified as priority wastes by the EU Commission.

Having consulted with the EEA, the EU Commission (DG Environment) and Eurostat, it was decided that further studies should concentrate on waste from electrical and electronic equipment (WEEE) for the following reasons:

- WEEE contributes to the production of several of the dangerous substances identified in this report;
- WEEE is of particular relevance to future waste planning because of the hazardous substances contained within the stream and the increasing amounts that are being generated; and
- WEEE composition is reasonably well defined;
- where insufficient data exists on waste generation, waste quantities can be estimated from production data;
- there is political interest in this waste stream as reflected in a draft Directive on WEEE

Annex A Legal standards for landfills

Legal standards Germany[28,29,30]

General principles
Basic principles of closed substance cycle waste management:

Waste must
1. be avoided; this must be accomplished especially by reducing its amount and toxicity;
2. be subjected to substance recycling or used to obtain energy.

The waste shall be pre-treated where this is required for recycling/reuse. If recycling/reuse is not possible even after prior treatment, waste may be managed in other ways. In this case, the waste is to be treated where necessary in such a way that its noxious and harmful components are eliminated, converted, segregated, concentrated or immobilised by thermal, chemical/physical or biological means so that, waste can be dumped without any detrimental effects to the well-being of the public. Attempts shall be made to reduce the total volume of the waste. It is prohibited to mix waste, waste has to be kept and collected separate for resource recovery and pollutant extraction.

Waste disposal facilities
For purposes of disposal, waste may be treated, stored or landfilled only in authorised plants or facilities (waste disposal facilities). In addition, treatment of waste for disposal is permitted in facilities that primarily serve a purpose other than waste disposal and require a license pursuant to the Federal Immission Control Act.

There are special requirements on the **organisation** and **personnel** of waste management facilities (e.g. precondition of structural and operational organisation) as well as on information and documentation.

Above-ground storage
- **Constructional requests**

Depending on the dangerousness, the wastes have to be dumped on different landfills. For municipal wastes, there are two landfill classes. Less dangerous wastes can be dumped on landfill class I, the more dangerous wastes on landfill class II. The hazardous wastes can only be dumped on landfills for hazardous wastes.

Landfills must be planned, installed and operated in such a way that by
a) selecting geologically and hydrogeologically suitable locations,
b) selecting suitable landfill sealing systems,
c) selecting suitable waste dumping techniques and
d) observing the allocation values of each landfill type

several extensively independent barriers are created and the release and dissemination of pollutants are prevented by the best available technology.
Concerning a) <u>Geological substratum:</u>

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[28] Act for Promoting Closed Substance Cycle Waste Management and Ensuring Environmentally Compatible Waste Disposal (KrW-/AbfG), 1994.

[29] Second General Administrative Provision on the Waste Avoidance and Waste Management Act (TA Abfall), 1991.

[30] Technical Instructions on Waste from Human Settlements (TA Siedlungsabfall), 1993.

There are different requirements on the geological substratum: for landfills of class II, the landfill bearing surface must have a higher pollution retention capacity than for landfills of class I. Landfills for hazardous waste need a geological barrier of at least 300 cm.

Concerning b) Landfill sealing systems:
Below the drainage layer, there are different requirements, too. For the landfill of class I, a mineral sealing layer of at least 50 cm (two layers) is sufficient. Landfills of class II need a protective layer, a plastic sealing web and below a mineral sealing layer of at least 75 cm (three layers). For landfills for hazardous waste, the mineral sealing layer must be raised to at least 150 cm.

Concerning c) Waste dumping techniques:
The formation of leachate is to be minimised upon building the landfill body so as to restrict the mobilisation of pollutants in the deposited wastes and reduce the effort and expenditure required for any necessary leachate treatment.

Concerning d) Allocation values: / Allocation criteria for dumping
Adherence to the allocation values is, in particular, designed virtually to prevent the formation of landfill gas, keep organic leachate pollution as low as possible and minimise settlement as a result of the biodegradation of organic components in the deposited wastes.

Waste may be allocated to ground-level dumping if the allocation parameters are met. Apart from these parameters there are several criteria, which should be observed:

- Waste, which because of its origin or constitution, is likely to damage the common good during its storage in view of its toxic, long-life or bioaccumulating substances (e.g. organic halogenated compounds, organic phosphorous compounds) shall not be allocated to ground-level dumping;
- the give off of odours

- **Organisational requests**

An operation plan shall be drawn up. The operation plan shall contain all important provisions for the operation of the dumping site, in particular for the construction of the body of the dumping site, for the collection and run-off of gas, leachate and other types of waste water pursuant and for the type and extent of internal control.

- **Special requests to protect the ground water**[31]

The deposition of the following substances is only allowed if there are special precautions referring to the state of the art:

[31] 1. AbfVwV (Anforderungen zum Schutz des Grundwassers bei der Lagerung und Ablagerung von Abfällen), 1990.

Register I:

1. organic halogen compounds and substances which react with water to such compounds
2. organic compounds with phosphorus
3. organic compounds with tin
4. substances, which have a carcinogenic, mutagene or teratogene effect with or in water
5. mercury and its compounds
6. cadmium and its compounds
7. mineral oils and hydrocarbons
8. cyanide.

Register II:

1. The following metals and their compounds: zinc, copper, nickel, chromium, lead, selenium, arsenic, antimony, molybdenum, titanium, tin, barium, beryllium, boron, uranium, vanadium, cobalt, thallium, tellur, silver.
2. Pesticides, disinfectants and other biocides as well as derived compounds if not listed in register I.
3. Substances with a detrimental effect on the taste and/or the smell of the ground water.
4. Toxic or long-lived organic compounds of silicon and substances, who build such compounds in water with the exception of such substances, which are biological harmless or quickly change in water in biological harmless substances.
5. Inorganic compounds with phosphorus.
6. Fluoride
7. Ammonia and nitrite

Objectives:

- Register I: to prevent the indirect draining off of the named substances
- Register II: to prevent damage to human beings and the environment by indirect draining off of the named substances
- to guarantee the monitoring of the ground water, special of his quality

- **Monitoring requests**

The following monitoring facilities must in general be provided and checked at regular intervals for proper operation.

- groundwater monitoring system
- monitoring settlements and deformations in the landfill body
- monitoring settlements and deformations in the landfill sealing systems
- recording meteorological data
- recording the quality of leachate and other waters
- monitoring the temperature at the landfill base

- **Requests on landfill closure and aftercare:**

After closing down the landfill, it shall be necessary to seal off the surface and install the monitoring facilities. During the aftercare phase, it shall, in particular, be necessary to implement and document long-term protection measures and checks in relation to landfill behaviour.

Underground dumping sites in salt rock for waste requiring special supervision

They are used to keep away permanently hazardous waste from the biosphere. Underground dumping shall be carried out in such a way that no post-operational care is required. Waste may be allocated to underground dumping sites

- if it contains no pathogens of communicable diseases or can allow such pathogens to arise;
- if, depending on the type of installation and the specific dumping conditions, it is adequately stable for dumping or reaches this stability in the final stage;
- if the waste is not, under dumping conditions (temperature, humidity), self-igniting or self-combustible;
- if the waste is not explosive under dumping conditions (temperature, humidity);
- if there are no reactions among the waste material or reactions among waste material and salt rock.

In the 'Second General Administrative Provision on the Waste Avoidance and Waste Management Act', there are preconditions for some wastes to dump in underground storage. This concerns mainly the following waste materials (particular waste with a high water-soluble portion):

- solid reaction products from flue gas cleaning
- filter dust from incineration plants for waste requiring special supervision
- special sludge
- batteries and accumulators
- residues containing mercury or PCB
- saline materials
- pesticides
- inorganic pigments
- lab and chemical residues
- catalysts
- inorganic residues of destination

Legal standards Austria

General principles

The Austrian Waste Management Act (AWG) entered into force on 1 July 1990. § 1 of the Act defines the following objectives:

- To keep detrimental, unbeneficial or otherwise unhealthy influences on man, as well as on animals, plants, their living conditions and their natural environment as low as possible;
- to preserve raw material and energy resources;
- to keep the demand for landfill capacities as low as possible;
- to ensure that only such materials should remain as waste, the dumping of which does not present any potential hazard for future generations (precautionary principle)

These objectives should be achieved on the basis of the following principles:

1. To keep the waste volumes and their pollutant contents as low as possible (qualitative and quantitative waste prevention);
2. To recycle waste in any way that is ecologically beneficial and technically possible, provided the additional costs are not unreasonable compared with other methods of waste disposal, and that a market for the secondary raw materials exists or can be created (recycling);
3. To treat waste that cannot be recycled with biological, thermal or chemical-physical methods; solid residues should be dumped in such a way that the are as inactive as possible, and separated according to condition (waste disposal).

The Waste Management Act thus places the highest priority on the protection of human beings and the environment and upon the preservation of natural resources. Accordingly, it must be the aim of waste management to handle waste in such a way that environmental pollution is kept as low as possible by avoidance, recovery and disposal.

Landfill
The Austrian Landfill Ordinance defines the state-of-the-art concerning the deposit of wastes and came into force on January 1st, 1997. Owners of already existing landfills had to decide by 1.1.1998 whether to adjust their landfill to these requirements according to a step-by-step plan or to close their landfill before 1.7.1999.

Landfills for excavated soil and for demolition wastes must be adapted until 1.7.1999. So called Residual-materials landfills and Mass-waste landfills have to fulfil the total of the criteria before 1.1.2004.

Types of landfills
In Austria, 4 types of landfills have been established:
– excavated-soil landfills
– demolition-waste landfills
– residual-materials landfills
– mass-waste landfills.

Site requirements
Besides the suitability of the geological and hydrological location, requirements concerning the substratum are to be fulfilled by Residual-materials and Mass-waste landfills (5 m with $k_f < 10^{-7}$ or 3 m with $k_f < 10^{-8}$ m/s).

Landfill sealing
Demolition-waste landfills need a mineral bottom sealing system of > 50 cm (two plies). Residual-materials and Mass-waste landfills have to be equipped with a composite sealing system consisting of a mineral sealing layer of at least 3 plies with an overall thickness of at least 75 cm, as well as a PE-HD synthetic liner with a minimum thickness of 2,5 mm.

Quality of wastes
Most important are the requirements for the quality of wastes to be dumped. The limit values for each landfill type are listed in table A.2. Depending both on total pollutant contents and eluate concentrations, wastes may be allocated to a specific landfill type. Note that the type Residual-materials landfill is designed for wastes which may be high in total contents, if the eluate values are rather low. The type Mass-waste landfill is made for wastes with a limited content of pollutants, whereas the eluate values are less restricted.

Waste which does not meet the criteria as shown in the tables must be pre-treated. Special provisions have been established for solidified wastes (e.g. with hydraulic binders) especially concerning long-term durability.

The limitation of the TOC with maximum of 5 % is of great importance and stresses the need to increase incineration and energy recovery. However, in Austria there exists a certain exemption rule in order to enable mechanic-biological pre-treatment. Waste originating from such treatment may be dumped in separated cells of Mass-waste landfills, to the extent that the combustion value (upper calorific value) of these wastes, determined from dry substance, does not exceed

6000 kJ/kg. Due to this clause, mechanic-biological treatment of municipal solid waste has to take place under the condition that the light weight fraction must be separated for incineration; the remaining fraction must show extensive biodegradation. Currently, comprehensive research is in progress in order to establish parameters and limit values for the residual bioactivity.

Waste acceptance inspection
Detailed regulations for the waste acceptance procedure have been established. The so-called comprehensive assessment for each individual waste has to be undertaken in such a way that the composition and the expected behaviour of the waste in the landfill can be determined. A careful entrance inspection including identity checks and the retaining of samples has to be undertaken and documented.

Further provisions
Further provisions deal with water management, surface sealing, landfill operation, requirements for the personnel (esp. the head of the acceptance inspection), monitoring and documentation. Last but not least there is a section dealing with the licensing procedure and the external supervision.

Legal standards Spain

Legislation on technical and administrative requirements that a landfill must comply.

There are no specific technical requirements for above ground storage landfills enforced by a national law. However based on other European legislation, Catalonia developed in 1997 a specific Decree with technical requirements for landfills. Following are described most of the requests, according to Decree 1/1997 in Catalonia. No legislation is available regarding underground storage landfills.

Constructional and waste acceptance requests
In Catalonia, landfills are classified in three classes depending on the dangerousness of waste. Class I corresponds to landfill containing inert waste, Class II no hazardous waste, and Class III hazardous waste.
The technical requirements before, during, and after the landfill construction depends on the landfill classification as described below; however, there are general trends which apply to all classes of landfill.

Landfills must be planned, installed and operated in such a way that by
a) selecting geologically and hydrogeologically suitable locations,
b) selecting suitable lining and drainage systems for the landfill,
c) selecting suitable sealing systems for the landfill,
d) selecting suitable waste dumping techniques and
e) observing the allocation value of each landfill type.

<u>Geological substratum:</u>
There is no difference on the geological substratum requirements for the three classes of landfill. All of them require a deep study on the geology and hydrogeology of the location.

<u>Waste dumping techniques:</u>
The formation of leachate is to be minimised upon building the landfill body so as to restrict the mobilisation of pollutants in the deposited wastes and reduce the effort and expenditure required for any necessary leachate treatment.

Allocation values:
Criteria for waste acceptance into the three classes of landfill are based on the values presented in

Tab. A.2. The geomechanic characteristics are not considered as a criteria for acceptance of the waste into the landfill; however, the chemical characteristics are taken into account.

Landfill infrastructure and conditioning:
For the landfill construction several considerations should be taken into account such as monitoring wells, reservoir for eluate storage, decanting reservoir for pluvial water, collectors and evacuation of fermenting gases, etc.

Requests before and during landfill activity
For proper operation of landfills, the following monitoring facilities must, among others, be provided and checked at regular intervals:

- Monitoring of waste quality (composition, source, characteristics, etc.) and amount at the entrance of the facility
- Groundwater monitoring system
- Monitoring settlements and deformations in the landfill body
- Recording meteorological data
- Recording the quality and flow of leachate and other waters
- If necessary, sampling and monitoring the generation and accumulation of fermenting gases.

Requests on landfill closure and aftercare:
After closing down the landfill, it shall be necessary to seal off the surface and install the monitoring facilities. During the aftercare phase, it shall, in particular, be necessary to implement and document long-term protection measures and checks in relation to landfill behaviour. There is a requirement for maintenance and regularly monitoring of the landfill.

Legal standards Denmark

General principles
Until 1997 landfills have been classified into 3 different types:

- Mono-landfill for a single type of waste (e.g. slag from coal-fired power station)
- Disposal tips for inert waste (e.g. demolition waste)
- Landfill for other kind of solid wastes.

Disposal tips could have been established without a membrane system.
For monolandfill and landfill for other kind of solid wastes their exist technical guidelines for preliminary investigations for new landfills, arrangement and layout, membrane systems, leachate collections, gas management, operations, control and inspections and restorations after the landfill has been filled up. All the requirements should have been incorporated in the environmental approval.

An overall national strategy for waste landfills is described in a new 'Danish Guidelines for Waste Landfills' 1997 from the Danish Environmental Protection Agency. The starting point for the strategy for waste disposal 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.

Compared to the old guidelines a new element in the strategy has been introduced. The properties of the waste must be known – including the potential leaching properties of the waste. This means that knowledge of the waste becomes the most important factor in the environmental protection.

Acceptance criteria for waste are one of the fundamental factors. Only certain types of waste can be accepted for deposit. This waste is classified in different categories according to the properties of the waste.

The acceptance criteria is detailed knowledge of the chemical composition and expected leaching profile of the waste. For the time being this basis is available for only a few types. Until the development of criteria and test methods are complete, the acceptance procedure for landfill waste must rely on positive lists.

Generally speaking, three categories are established – with the following characteristics:

Category I: Inert waste, is
inorganic waste containing no reactive (neither physically or chemically) substances. The discharge of substances and the eco-toxicity must at all times be negligible.

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.

Category III: Mixed waste, is
a mixture of organic and inorganic substances which cannot be separated or can be separated only with difficulty and with a disproportionate consumption of resources. The waste must have unlimited content of organic, slowly degradable substances and must not have a high content of readily soluble mineral components.

Examples of types of waste:

Category I	Category II	Category III
asbestos porcelain glass	gypsum waste slag road sweep-up	residual products from sorted bulky waste sand from treatment plants

CRITERIA	CATEGORY I	CATEGORY II	CATEGORY III
	Inert Waste	**Mineral Waste**	**Mixed Waste**
Ignition loss	< 2 %	< 5 %	20 %[1)]
Cont. of substances harmful to the environment	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 can not be verified.

Instead, an assessment in terms of volume must be made related to the ignition loss.
Desired organic half-life > 15 years

A: The waste must not be capable of discharging (by evaporation, dissolution or leaching) significant quantities of substances harmful to the environment (neither organic or inorganic).

B: The waste should not be capable of discharging (by evaporation, dissolution or leaching) significant quantities of substances harmful to the environment (neither organic or inorganic).

C: The waste's quantitative content of potentially leachable contaminating components and their identity should be known. Significant quantities of inorganic substances – including salts and micronutrients – must not be leachable from the waste – in the short or long term.

D: The waste's quantitative content of potentially leachable contaminating components 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 long term should be described, at least as a type (oxidising/reducing, pH/alkalinity).

F: 95 % of the total chemical composition of a waste 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 the leachate should not at any time have any significant ecotoxilogical effect, and it must be rendered probable that the leachate at all times be accepted direct in the groundwater around the landfill.

H: It should be rendered probable that the leachate can be accepted within a period of not more than 30 years in the groundwater around the landfill.

'Waste landfills' is the collective terms for facilities intended for waste depositing. It is no longer possible to establish disposal tips. Acceptance criteria for waste are one of the fundamental factors in the national Danish Guidelines. In the future only certain types of waste can be accepted for deposit. This waste is classified in different categories according to the properties of the waste. A comprehensive test programme divided into levels has been developed for the assessment of waste for landfills.

Waste that can be dealt with in other environmentally sound manner by means of existing methods should not be dumped. Waste which is suitable for incineration and recycling should not be dumped. In special cases, a mono-landfill may be set up for large quantities of a single type of waste.

Legal standards Ireland

All landfill activities in Ireland require or will require a licence from the Environmental Protection Agency under the Waste Management Act, 1996. The licensing system is being phased in over a period of time with all landfills requiring a licence by March, 1999. The Agency cannot grant a licence unless it is satisfied that:

- any emission from the activity will meet any relevant standards or emission limit value set under any other legislation,
- the activity will, if operated in accordance with conditions set by the Agency in a licence, not cause environmental pollution,
- the best available technology not entailing excessive costs will be used to prevent or eliminate or, where that is not practicable, to limit, abate or reduce an emission from the activity,
- the applicant is a fit and proper person to hold a licence,
- the applicant has complied with the licensing regulations set by the Minister for the Environment.

The Agency is considering preparing BATNEEC guidance for the following activities:

- landfill sites accepting municipal waste and/or industrial waste
- landfill sites accepting only inert wastes
- waste transfer stations (municipal and/or industrial wastes)
- health care risk waste disposal facilities (other than incineration)
- hazardous wastes disposal facilities

BATNEEC guidance will, in respect of the activities listed above:

a) consider the meaning of the term BATNEEC in the Waste Management Act 1996, having regard to other information, and assess its application in respect of each activity;
b) consider other appropriate written material which will assist in this matter;
c) consider the nature of emissions from such activities and determine how the BATNEEC concept should apply to them;
d) consider the applicability of setting emission limit values for significant emissions; and
e) identify technologies appropriate for the control of emissions, along with methods of maintenance, use, operation and supervision which fulfil this purpose.

BATNEEC guidelines prepared to date by EPA, for activities licensable under the EPA Act, 1992, are in the format set out below. Allowance is made for any additional topics which may need to be added as a result of research/issues arising during the preparation of the guidelines.

- Introduction
- Interpretation of BATNEEC
- Sector covered by the Guidance Note
- Sources and Emissions
- Control Technologies
- Determination of Emission Limit Values (where appropriate)
- Compliance Monitoring
- Appendices and schedules as required.

BATNEEC Guidelines issued by the EPA identify the major sources of emissions to land, air and water. The identified list is not all encompassing, nor will every unit have every one of the emissions which are associated with the activity. Emissions are generally considered under two headings; fugitive or unscheduled emissions, and specific activity emissions.

The objective of the BATNEEC Guidelines is to provide a list of technologies which will be used by the EPA to determine BATNEEC for an activity. The section on 'Control Technologies' identifies technologies and good practices to prevent, eliminate, reduce, abate or limit emissions that may arise in the activity.

Technologies identified in the BATNEEC guidelines are considered to be current best practice. These technologies are representative of a wide range of currently employed technologies appropriate to particular circumstances. However, the guidance issued in respect of the use of any technology, technique or standard does not preclude the use of any other similar technology, technique or standard. The choice of a specific technology / technologies, depends on a wide range of circumstances but the crucial factor is that the selected regime achieves BATNEEC.

In applying BATNEEC, Environmental Quality Objectives (EQOs) and Environmental Quality Standards (EQSs), where set, must be respected. Measures, such as operational practice changes, improved waste handling and storage practices, may also be employed to prevent or effect reductions in emissions. As well as providing for the installation of equipment, and the operation of procedures for the reduction of possible emissions, **BATNEEC will also necessitate the adoption of an on-going programme of environmental management and control**, which must focus on continuing improvements aimed at prevention, elimination and progressive reduction of emissions. In the identification of BATNEEC, emphasis is placed on pollution prevention techniques, including cleaner technologies and waste minimisation, rather than end-of pipe treatment.

BATNEEC guidelines may specify emission limit values (ELVs) for different media. These values then become the criteria/performance standards which the applied or associated technologies must meet or surpass. In some cases it may not be practicable to specify ELVs, for example the emission of landfill gas from the landfill body to air, as it would not be practicable to measure it over the entire landfill body. However, it may be possible to specify ELVs for individual elements, e.g. parameter concentrations in surface water discharge, or combustion products from flarestacks.

Monitoring is required to ensure that the selected technology is performing adequately and to demonstrate that ELVs, where specified, or any other applicable standards are being achieved. Compliance monitoring may be scheduled as continuous or periodic. Monitoring requirements must have regard to existing standards, legislation and conditions attached to a licence as any emission from a licensed activity must not result in contravention of any relevant standard or any relevant emission value, prescribed under any enactment, or must not cause environmental pollution.

The technologies and emission limit values (ELVs) identified are regarded as representing BATNEEC for a *new* activity. However, it is also generally envisaged that *existing* activities will progress towards the use of similar technologies and attainment of similar emission limit values, but the specific requirements and associated time frames will be identified on a case by case basis when the licence application is being processed. For existing activities consideration must be given to the nature, extent and effect of emissions, the nature and age of the existing facilities, and the costs which would be incurred in improving or replacing these facilities. Furthermore, for *all* activities, additional or more stringent requirements may be specified on a site-specific basis whenever environmental protection so requires. Hence the BATNEEC Guidelines are not the sole basis on which licence conditions are to be set, since information from other sources will also be considered; such information includes site-specific environmental and technical data, financial data and other relevant information. All of these are taken into account by the EPA in deciding the licence and setting appropriate conditions.

BATNEEC will change with time, particularly in the light of technical advances. It is intended to update the guideline notes as required in order to incorporate technological advances as they occur.

In addition to BATNEEC Guidelines, regard must be given to landfill manuals prepared by the Environmental Protection Agency under Section 62 of the EPA Act, 1992. These manuals provide guidance on all aspects of landfilling from investigation to site selection, site design, monitoring and aftercare. The following manuals are being or have been prepared by the EPA and their current status is listed below:

- Landfill Monitoring (published 1996)
- Investigations for Landfill (published 1996)
- Landfill Operational Practices (published 1997)
- Waste Acceptance (to be published 1998)
- Site Selection (to be published 1998)
- Site Design (to be published 1998)
- Restoration & Aftercare (draft, to be circulated for review in 1998)

Legal standards landfill technical data

d: thickness; k_f permeability correction value; k: permeability coefficient: nr: not required

	Austria	Spain 1 – Catalonia	Germany	Ireland	Denmark	EU
Regulation	Landfill Ordinance 1.1.1997	Decree 1/1997	TA Abfall TA Siedlungsabfall	EPA Criteria for Landfills (section 62 EPA Act); S.I. 133 of 1997		
Classification of landfills	4 types: excavated soil demolition waste (D) residual waste (R) mass-waste (M)	3 types: class III hazardous/ class II: non hazardous/ class I: inert waste	3 types: hazardous waste (H) for waste from human settlements; class II: with higher organic content as in class I	3 Types: Hazardous; Non-Hazardous (biodegradable); Inert.		
Underground	requirements on geological and hydrological location R, M: d = 5 m and k_f< 10^{-7}m/s or d ¤3 m and k_f<10^{-8} m/s	requirements on geological and hydrological location; d >5 m/>2 m/>1 m k_f < 10-^{9} /< 10-^{9} /<10^{-7} m/s	requirements on geological and hydrological location H: d >3 m, k_f< 10^{-7}m/s	criteria specified on geological and hydrological location: d ≥ 5 m/ ≥ 1 m/ ≥ 1 m k_f≤ 1 x 10^{-9} m/s / 1 x 10^{-9} m/s / 1 x 10^{-7} m/s		
Sealing systems						
a) bottom						
Mineral sealing layer	D: d = 0.5 m (two plies) R, M: d = 0.75 m (three plies)	d> 1.5m/>0.9/>0.5m; k < 10-^{10} /< 10-^{10} m/s / nr	H: d = 1.5 m, k = 5*10^{-10} m/s II: d = 0.75 m (three plies) k = 5*10^{-10} m/s I: d = 0.5 m (two plies)	d ≥ 1.5 m/ ≥ 1 m/ nr		
Security layer	-	d> 20 cm/nr/nr	-			
Plastic layer	R, M: d = 2.5 mm	III: d = 2.5 mm II: d= 1.5 mm I: nr	H, II: d = 2.5 mm I: nr	Required for hazardous and non-hazardous landfills (composite liners)		
Water drainage system		d = 0.3 m k: >10^{-3} m/s	H, II, I: d = 0.3 m k = 10^{-3} m/s	d ≥ 0.5 m/ 0.5 m/ nr k ≥ 10^{-3} m/s /10^{-3} m/s/ nr		
Protective layer		required	H, II: required	if necessary		
Drainage layer				see above for d and k criteria		
b) surface						
Gas drainage		if necessary	if necessary	Haz: if neccessry Non Haz: yes Inert: not specified		
Equalising layer			H, II, I: d =¤ 0.5 m			
Mineral sealing layer		III, II: d = 0.9 m; I: d = 0.3 m; II, II, I: k = 10-9 m/s	H: d ¤ 0.5 m; k = 5*10^{-10} m/s II: d = 0.5 m;	d: 0.6 m/ 0.6 m/not specified		

	Austria	Spain 1 – Catalonia	Germany	Ireland	Denmark	EU
			$k = 5*10^{-9}$ m/s	k: ≤ 1 x 10^{-9} m/s / 1 x 10^{-9} m/s / not specified		
Plastic layer		III: d = 2 mm (if necessary)	H, II: d = 2.5 mm I: nr	Yes for non-haz (composite system) If necessary for hazardous		
Drainage layer			H, II, I: d = 0.3 m	d ≥ 0.5 m / ≥ 0.5 m/ not specified		
Recultivation layer			H, II, I: d = 1 m	d ≥ 1 m/ ≥ 1m/ ≥ 0.5 m (150-300 mm top soil)		
Settling layer		d = 0.5 m;				
Criteria for waste acceptance	depend on landfill class criteria based on waste and on eluate	depend on landfill class; criteria based on waste and on eluate	depend on landfill class; criteria based on waste and on eluate	Depends on landfill class; criteria based on waste		
Chemical	yes	yes	yes	yes		
Physical	?	?	yes	yes		
Geomechanic		no				
Landfill bans			wastes, which give off offensive odours or which are likely to damage common good in view of their toxic long-life or bioaccumulating substances (e.g. halogenated compounds) s. also allocation values			
Requests on infrastructure and conditioning		yes	yes	yes		
Requests on waste inspection			yes	yes		
Requests before and during landfill activity		monitoring waste quality and amount, ground-water, settlements, deformation; document meteorological data, quality and flow of leachate and other waters, if necessary sampling and monitoring the generation of fermenting gases	waste register, monitoring ground-water, settlements, deformation, meteorological data, amount and quality of leachate and other waters, temperature, landfill gas	Yes. Criteria based on landfill guidance manuals and on licences issued by the EPA.		
Requests on landfill closure and aftercare		yes	yes			

Tab. A.1: Legal standards

Allocation values
Criteria for acceptance based on waste

	AUSTRIA					SPAIN			Germany		
landfill type Parameter	excavated soil I	II	demolition waste	residual	mass	class I	class II	class III	hazard. waste	class II	class I
Loss 105°C						65 %	65 %	65 %			
Loss 500°C-105°C						5 (2) %	15 (3) %	15 (3) 5			
Ignition value						>= 55°C	>= 55°C	>= 55°C			
Ignition loss									10 %	5 %	3 %
Vane shears strength									≥ 25 kN/m²	≥ 25 kN/m²	≥ 25 kN/m²
Axial deformation									≤ 20 %	≤ 20 %	≤ 20 %
Uniaxial compressive strength									≥ 50 kN/m²	≥ 50 kN/m²	≥ 50 kN/m²
Limit Value (mg/kg Dry Matter)											
Dry residue	8.000	8.000	25.000	30.000	100.000				10 %	6 %	3 %
Arsenic (as As)	50	200	200	5 000	500	<250	<2.000	-			
Barium (as Ba)					10.000						
Lead (as Pb)	150	500	500		3.000	< 2.000	< 5 %				
Cadmium (as Cd)	2	4	10	5 000	30	< 50	< 1.000				
Chrome total (as Cr)	300	500	500		5.000	< 3.000	< 5 %				
Cobalt (as Co)	50	----	100		500						
Copper (as Cu)	100	500	500		5.000	< 6.000	< 6 %				
Nickel (as Ni)	100	500	500		2.000						
Mercury (as Hg)	1	2	3	20	20	< 25	< 250				
Silver (as Ag)	500	1.000			50						
Zinc (as Zn)	500	1.000	1.500		5.000	< 8.000	< 7.5 %				
Total of organically bound carbon TOC (as C)	20.000		30.000	30.000	50.000					≤ 3 %	≤ 1 %
Total of hydrocarbons	20		100	5.000	20.000						
Total of polycyclical aromatic hydrocarbons (PAK)	0.5		2.0	see note	100						
Organically bound halogens amenable to stripping (POX)) (as Cl)					1.000						
Lipophile substances						0.5 %	4 %	10 %	≤ 4 %	≤ 0.8 %	≤ 0.4 %
Hal.vol.org.comp.						≤ 0.05 %	≤ 0.1 %	≤ 1%			
no hal.vol.org.com.						≤ 0.15 %	≤ 0.3 %	≤ 3 %			

Criteria for acceptance based on eluate

	AUSTRIA				SPAIN			Germany		
landfill type Parameter	excavated soil I II	demolition waste	residual	mass	class I	class II	class III	hazard. waste	class II	class I
pH value	6.5 - 11	6 - 13	6 - 12	6 to 13	5.5 - 12	4 - 13	4 - 13	4 - 13	5.5 - 13	5.5 - 13
Electric conductivity	150 mS/m	300mS/m	1.000 mS/m		≤ 6.000 µS/cm	≤ 50.000 µS/cm	≤ 100.000 µS/cm	≤ 100.000 µS/cm	≤ 50.000 µS/cm	≤ 10.000 µS/cm
Limit Value (mg/kg Dry Matter)										
Total of organically bound carbon TOC (as C)	200	500	500	see note below	≤ 40 mg/l	≤ 100 mg/l	≤ 200 mg/l	≤ 200 mg/l	≤ 100 mg/l	≤ 20 mg/l
Total of hydrocarbons	5	50	100							
EOX (as Cl)	0.3	3	see note	30						
Anion-active tenside (as TBS)	1	5	20	see note below						
Index phenols					≤ 1 mg/l	≤ 10 mg/l	≤ 50 mg/l	100	50	0.2
AOX					≤ 0.3	≤ 1.5	≤ 3	3	1.5	0.3
Aluminium (as Al)	5.0	20.0	100.0							
Arsenic (as As)	0.5	0.75	1.0		≤ 0.1	≤ 0.5	≤ 1	≤ 1	0.5	0.2
Barium (as Ba)	10.0	20.0	100.0							
Lead (as Pb)	1.0	2.0	10.0		≤ 0.5	≤ 1	≤ 2	≤ 2	1	0.2
Boron (as B)		30.0								
Cadmium (as Cd)	0.05	0.5	1.0		≤ 0.1	≤ 0.2	≤ 0.5	≤ 0.5	0.1	0.05
Chrome, total (as Cr)	1.0	2.0	20.0		≤ 0.5	≤ 2	≤ 5			
Chrome, hexavalent (as Cr)	0.5	0.5	1.0	20	≤ 0.1	≤ 0.1	≤ 0.5	≤ 0.5	0.1	0.05
Cobalt (as Co)	1.0	2.0	5.0							
Iron (as Fe)	10.0		20.04	see note below						
Copper (as Cu)	2.0	10.0	10.0		≤ 2	≤ 5	≤ 10	≤ 10	5	1
Nickel (as Ni)	1.0	2.0	10.0		≤ 0.5	≤ 1		≤ 2	1	0.2
Mercury (as Hg)	0.01	0.05	0.1		≤ 0.02	≤ 0.05		0.1	0.02	0.005
Silver (as Ag)	0.2	1.0	1.0							
Zinc (as Zn)	10.0	20.0	100.0		≤ 2	≤ 5		10	5	2
Tin (as Sn)	2.0	10.0	20.0							
Ammonium (as N)	8	40	100	10.000	≤ 5	≤ 200	≤ 1.000	1.000	200	4
Chloride (as Cl)	2.000	5.000	1		≤ 500	≤ 5.000	≤ 10.000	10.000		
Cyanide, easily releasable (as CN)	0.2	1	100	20	≤ 0.1	≤ 0.5	≤ 1	1	0.5	0.1
Fluoride (as F)	20	50	100	500				50	25	5
Nitrate (as N)	100	500	see note	note						
Nitrite (as N)	2	10	15	1.000	≤ 3	≤ 10	≤ 30	30		
Phosphate (as P)	5	50	50	note						
Sulphate (as SO_4^{2-})		5.000		25.000	≤ 500	≤ 1.500	≤ 5.000	5.000		

Note: to be determined in the course of the authorisation proceedings, should this parameter be relevant for the wastes to be deposited

Tab. A.2: Allocation values

Annex B Legal standards for incineration

Legal standards in selected European countries

Emission Standard:

country	EU	Germany	Denmark	France	Nether-lands	Austria	Sweden	Switzer-land
regulation	**ruling 94/67/EG 1994**	**17. BImSchV 1990**	**1991**	**1991 < 3 t/h**	**BLA 1993**	**LRV-K 1998/1990 0.75 - 15 t/h**	**1993 = 3 t/h**	**LRV 1992 > 350 kW**
dangerous substances								
dust	10	10	30	30	5	20	20	10
hydrogen chloride (HCl)	10	10	50	50	10	15	100	20
hydrogen fluoride (HF)	1	1	2	2	1	0.7	-	2
carbon monoxide (CO)	50	50	100	100	50	50	100	CO/CO_2 <0.002
organic substance (total C)	10	10	20	20	10	20	-	20
sulphur dioxide (SO_2)	50	50	300	300	40	100	-	50
nitric oxides (NO_x)	-	200	-	-	70	300	-	80
dioxins/furans PCDD/PCDF (in ng TE/Nm³)	0.1 from 1.1.1997 respite: 1.9.98	0.1	0.1	-	0.1	0.1	0.1	-
heavy metals:								
Cd. Tl	altogether 0.05*	altogether 0.05*						
Hg	altogether 0.1 (0.05)*	altogether 0.05*						
As. Co. Cr. Cu. Mn. Ni. Pb. Sb. Sn. V	altogether 1.0 (0.5)*	altogether 0.5*						
reference	11 % O_2	11 % O_2	10 % O_2	9 % O_2	11 % O_2	11 % O_2	10 % CO	11 % O_2

* average value (in parenthesis: EU guiding rule for hazardous waste incineration. which had to be transposed till 31.12.1996)

Tab. B-1: Emission limiting values of selected dangerous substances (mg/Nm³ dry exhaust gas) for waste combustion in several European countries[32, 33]

Hazardous waste incineration

The European Commission has adopted a Proposal for an amendment to the 1994 Council Directive on the Incineration of Hazardous Waste. The existing legislation lays down very strict limit values for emissions of heavy metals and dioxins into the

32 UBA, Jahresbericht 1995, page 358.

33 Akademie für Technikfolgenabschätzung in Baden-Württemberg (M. Kaimer, D. Schade): Pilotstudie. Bewertung der thermischen Abfallbehandlung, Nr. 61, September 1996.

air. The proposed amendment seeks to limit the emissions into water of these toxic substances. In particular, the Proposal restricts the release of cadmium and mercury compounds and dioxins to the technically feasible minimum, in order to protect human health and the environment.[34]

The proposal from the Commission sets specific emission limit values for the pollutants contained in the waste water generated by the exhaust gas cleaning systems of plants for the incineration of hazardous waste. Discharges into the aquatic environment of waste water must be limited as far as possible, and the proposal sets out the strict conditions under which such discharges can take place. It also provides the necessary provisions for monitoring of emissions by sampling and analysis, as well as ensuring that the principle of non-transfer of pollution from air to water is respected.

The proposed limit values (monthly average) are as follows:
- mercury compounds: 0.01 mg/l,
- cadmium compounds: 0.02 mg/l,
- dioxins: 0.5 ng/l.

For a series of ten other heavy metals and their compounds antimony, arsenic, lead, chromium, cobalt, copper, manganese, nickel, vanadium, tin also covered by the proposal the total limit is 5 mg/l.

Cadmium and mercury compounds and dioxins are amongst the most toxic substances for ecosystems and human beings. The effects of dioxins are well known, in particular since the Seveso accident in Italy in 1976. They affect the central nervous system, cause liver damage and chloracne.

Heavy metals, such as mercury and cadmium, accumulate in the biosphere and in the kidneys and liver and can cause severe damage to these organs. The effects of mercury have been well known since the so called ‘Minimata-disease’ (named after a fishing village in Japan), where mercury accumulated in fish and caused paralysing effects and severe defective vision when consumed by the local population.

Realisation of European Union’s (EU) Hazardous Waste Directive in the countries:[35]

The Netherlands, the United Kingdom and Greece have failed to fully respect the deadline for adoption and communication to the Commission of the necessary national implementing legislation. This deadline was 31 December 1996. In the case of the Netherlands and Greece, no legislation has been received. The United Kingdom has communicated legislation for England, Scotland and Wales, but there is as yet no legislation covering Northern Ireland.

The Directive’s objective is to ensure that specified measures and procedures are in place at national level to prevent or reduce as far as possible negative environmental effects arising from hazardous waste incineration. The Directive addresses the pollution of air, soil, surface and groundwater and risks to human health, and aims to achieve a high level of environmental protection.

[34] DG XI Press Hazardous Waste Incineration: Commission proposes Amendment to the Directive on Hazardous Waste Incineration. http://europa.eu.int/en/comm/dg11/press/ip971048.htm, 11/1997.

[35] DG XI Press NL,UK,EL-Hazardous Waste Incineration: Commission decides further action against the Netherlands, the United Kingdom and Greece over hazardous waste incineration. http://europa.eu.int/en/comm/dg11/press/98578.htm, June 1998.