Section V

Guidance/guidelines by source category: Source categories in Part II of Annex C

Part II Source category (a): Waste incinerators

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Summary

Waste incinerators are identified in the Stockholm Convention as having the potential for comparatively high formation and release of chemicals listed in Annex C to the environment.

The potential purposes of waste incineration include volume reduction, energy recovery, destruction or at least minimization of hazardous constituents, disinfection and the recovery of some residues.

When considering proposals to construct new waste incinerators, priority consideration should be given to alternatives such as activities to minimize the generation of waste, including resource recovery, reuse, recycling, waste separation and promoting products that generate less waste. Priority consideration should also be given to approaches that prevent the formation and release of persistent organic pollutants.

The environmentally sound design and operation of waste incinerators requires the use of both best available techniques and best environmental practices (which are to some extent overlapping) to prevent or minimize the formation and release of chemicals listed in Annex C.

Best environmental practices for waste incineration include appropriate off site procedures (such as overall waste management and consideration of environmental impacts of siting) and on site procedures (such as waste inspection, proper waste handling, incinerator operation and management practices and handling of residues).

Best available techniques for waste incineration include appropriate selection of site; waste input and control; techniques for combustion, flue gas, solid residue and effluent treatment.

To achieve best results for environmental protection as a whole it is essential to coordinate the waste incineration process with upstream activities (e.g. waste management techniques) and downstream activities (e.g. disposal of solid residues from waste incineration).

Releases of chemicals listed in Annex C from municipal solid waste incinerators designed and operated according to best available techniques and best environmental practices occur mainly via fly ash, bottom ash and filter cake from wastewater treatment. Therefore it is of major importance to provide for a safe sink of these waste types, for example by pretreatment and final disposal in dedicated landfills, which are designed and operated according to best available techniques.

With a suitable combination of primary and secondary measures, PCDD/PCDF performance levels in air emissions no higher than 0.1 ng I-TEQ/Nm^3 (at 11% O_2) are associated with best available techniques. It is further noted that under normal operating conditions emissions lower than this level can be achieved with a well designed waste incineration plant.

Best available techniques for discharges of waste water from effluent treatment plants, receiving flue gas treatment scrubber effluents, are associated with PCDD/PCDF concentration levels well below 0.1 ng I-TEQ/l.

1. Introduction

Waste incinerators are identified in the Stockholm Convention as having the potential for comparatively high formation and release to the environment of chemicals listed in Annex C of the Convention. Also, co-incineration of waste can be a source of releases of chemicals listed in Annex C.

This section deals only with the dedicated incineration of wastes and not with other situations where waste is thermally treated, for example co-incineration processes such as cement kilns and large combustion plants, which are dealt with in the sections relating to those processes.

When considering proposals to construct new waste disposal facilities, the Stockholm Convention advises Parties to give priority consideration to:

- Alternatives such as activities to minimize the generation of municipal waste, including resource recovery, reuse, recycling, waste separation and promoting products that generate less waste, when considering proposals to construct new waste disposal facilities (Stockholm Convention, Annex C, Part V, section A, subparagraph (f)), and to;
- Approaches that will prevent the formation and release of chemicals listed in Annex C.

Waste management considerations, which are described in section III.C (ii) of the present guidelines, and the alternative approaches outlined in subsection 6 below, can be taken into account as part of overall waste prevention and control strategies.

2. Process description

Incineration is used as a treatment for a very wide range of wastes. Incineration itself is commonly only one part of a complex waste treatment system that altogether provides for the overall management of the broad range of wastes that arise in society (for consideration of cross-cutting issues related to waste incineration and management see section III.C of the present guidelines).

The objective of waste incineration is to treat wastes so as to reduce their volume and hazard, whilst capturing (and thus concentrating) or destroying potentially harmful substances that are, or may be, released during incineration. Incineration processes can also provide a means to enable recovery of the energy, mineral or chemical content from waste.

Incinerators come in a variety of furnace types and sizes as well as combinations of pre- and post-combustion treatment. There is also considerable overlap among the designs of choice for municipal solid waste, hazardous waste and sewage sludge incineration.

Incinerators are usually designed for full oxidative combustion over a general temperature range of 850 °C – 1,400 °C. This may include temperatures at which calcinations and melting may also occur. Gasification and pyrolysis represent alternative thermal treatments that restrict the amount of primary combustion air to convert waste into process gas, which may be used as a chemical feedstock or incinerated with energy recovery. However, compared to incineration, application of these systems is low and operational difficulties are reported at some installations.

Waste incinerator installations can be characterized by the following: waste delivery, storage, pretreatment, incineration/energy recovery, flue gas cleaning, solid residue management, and wastewater treatment. The nature of the input waste will have a significant bearing on how each component is designed and operated.

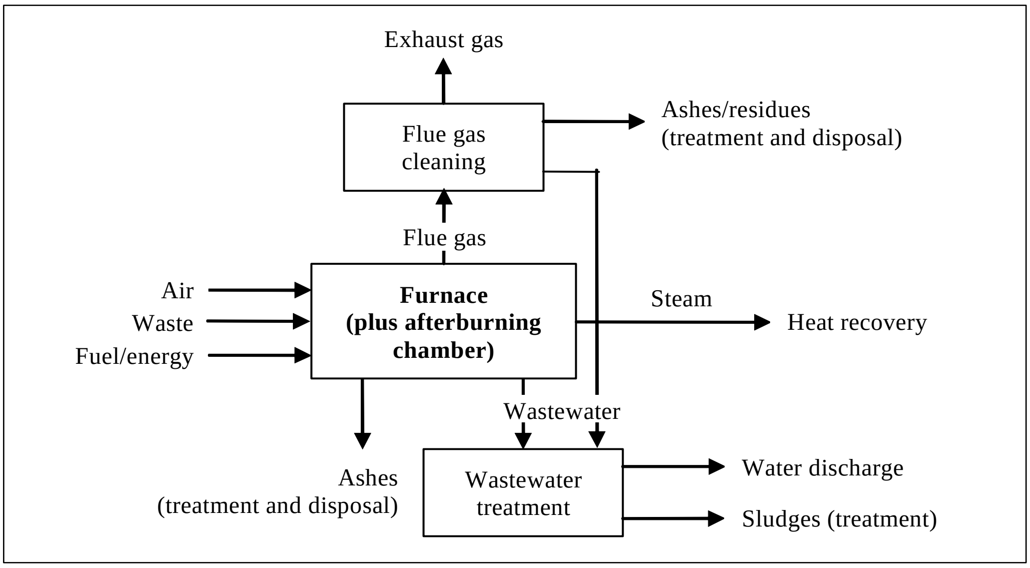
Waste is generally a highly heterogeneous material, consisting essentially of organic substances, minerals, metals and water. During incineration, flue gases are created that will contain the majority of the available fuel energy as heat.

In fully oxidative incineration the main constituents of the flue gas are water vapour, nitrogen, carbon dioxide and oxygen. Depending on the composition of the material incinerated , operating conditions and the flue gas cleaning system installed, acid gases (sulphur oxides, nitrogen oxides, hydrogen chloride), particulate matter (including particle-bound metals), and a wide range of volatile organic compounds, as well as volatile metals (such as mercury) are emitted. Incineration of municipal solid waste and hazardous waste has also been shown to lead to the unintentional formation and release of the persistent organic pollutants (PCDD/PCDF, PCB, HCB). In addition it has the potential to release polybrominated dibenzo-*p*-dioxins (PBDD) and polybrominated dibenzofurans (PBDF). Formation is normally substantially increased in units that are poorly designed or operated.

Depending on the combustion temperatures during the main stages of incineration, volatile metals and inorganic compounds (e.g. salts) are totally or partly evaporated. These substances are transferred from the input waste to both the flue gas and the fly ash it contains. A mineral residue fly ash (dust) and heavier solid ash (bottom ash) are created. The proportions of solid residue vary greatly according to the waste type and detailed process design.

Other releases are residues from flue gas treatment and polishing, filter cake from wastewater treatment, salts and releases of substances into wastewater. Figure 1 presents a simplified flow scheme of an incinerator.

Figure 1: Simplified flow scheme of an incinerator



2.1 Municipal solid waste incineration

Although in many areas landfilling of the non-recycled waste remains the principal means for the disposal of municipal solid waste, incineration and the subsequent landfilling of residues has become a common practice in many developed and industrializing countries. (For considerations of the waste hierarchy and recycling of waste see section III.C (ii)).

The European Council Directive on the landfill of waste (1999/31/EC) requires Member States to set up a national strategy for the implementation of the reduction of biodegradable waste going to landfills. This strategy should include measures to achieve the targets by means of, in particular, recycling, composting, biogas production and material or energy recovery.

Municipal solid waste incineration is commonly accompanied by the recovery of some energy (“waste to energy”) in the form of steam and/or the generation of electricity. Incinerators can also be designed to accommodate processed forms of municipal solid waste derived fuels, as well as co-firing with fossil fuels. Municipal waste incinerators can range in size from small package units processing single batches of only a few tons per day to very large units with continuous daily feed capacities in excess of a thousand tons. The capital investment costs of such facilities capable of meeting standards that may be considered best available techniques is normally in the range of millions to hundreds of millions of US$.

The primary benefits of municipal solid waste incineration are the destruction of organic (including toxic) materials, the reduction in the volume of the waste and the concentration of pollutants (e.g.

heavy metals) into comparatively small quantities of ashes, thus generating safe sinks if properly disposed of. The recovered energy can be an important additional benefit.

Large municipal waste incinerators are major industrial facilities and have the potential to be significant sources of environmental pollution (See Section 2).

2.1.1 Operational considerations for municipal solid waste incinerators

In many municipal solid waste incinerators other waste fractions such as bulky waste, (e.g. from sorting plants), sewage sludge or the high calorific fraction from waste pretreatment (e.g. from shredder plants) are also incinerated. These wastes have to be carefully evaluated prior to incineration to ascertain whether the waste incineration plant (including flue gas treatment, wastewater and residue treatment) is designed to handle these types of waste and whether it can do so without risk of harm to human health or the environment. Some important parameters are chlorine and bromine content, aluminium content, heavy metal content, calorific content and burnout behaviour. High concentration of bromine may lead to formation of brominated compounds such as polybrominated dibenzo-*p*-dioxins (PBDD) and polybrominated dibenzofurans PBDF. Neglecting the limits of the incineration plant will result in operational problems (e.g. the necessity of repeated shutdowns due to cleaning of the grate or heat exchangers) or in a bad environmental performance (e.g. high emissions into water, high leachability of fly ash).

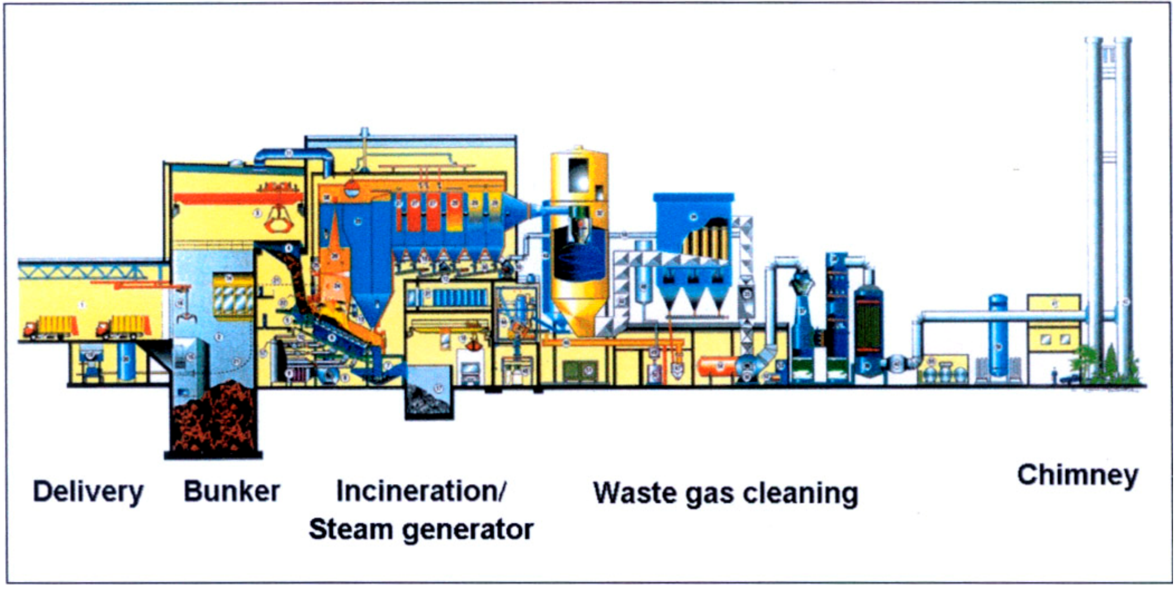
Figure 2 shows the typical layout of a large municipal solid waste incinerator.

2.1.2 Delivery, storage and pretreatment of municipal solid waste

Waste may be delivered to the incinerator by truck, by barge or rail. Recycling or source separation programmes upstream of waste delivery can significantly influence the efficiency of processing. Removing glass and metals prior to incineration will increase the per unit energy value of the waste. However, in some plants metals are separated from bottom ash after incineration. Recycling paper, cardboard and plastics will reduce the energy value of the waste but may also reduce available chlorine. Separating bulky wastes reduces the need for removal or shredding on site.

In addition to waste separation, pretreatment of mass burn municipal solid waste may include crushing and shredding to facilitate handling and homogeneity. Bunker storage areas are normally covered to protect against additional moisture and the facility is typically designed to draw combustion air through the bunker to reduce odour.

Figure 2. Typical municipal solid waste incinerator



Source: European Commission 2006

2.1.3 Municipal solid waste incinerator designs

Municipal solid waste can be incinerated in several combustion systems including travelling grate, rotary kilns, and fluidized beds. In the United States and in Asia modular incinerators, which burn waste without preprocessing, are also in use. Fluidized bed technology requires municipal solid waste to be of a certain particle size range – this usually requires some degree of pretreatment and the selective collection of the waste. Combustion capacities of municipal solid waste incinerators typically range from 90 to 2,700 tons of municipal solid waste per day (modular configurations: 4 to 270 tons per day).

Other processes have been developed that are based on the decoupling of the phases that also take place in an incinerator: drying, volatilization, pyrolysis, carbonization and oxidation of the waste. Gasification using gasifying agents such as steam, air, oxides of carbon or oxygen is also applied. These processes aim to reduce flue gas volumes and associated flue gas treatment costs. Many of these developments have met technical and economic problems when scaled up to commercial, industrial sizes, and are therefore pursued no longer. Some are used on a commercial basis (e.g. in Japan) and others are being tested in demonstration plants throughout Europe, but still have only a small share of the overall treatment capacity when compared to incineration.

2.2 Hazardous waste incineration

Incineration and other forms of thermal treatment also represent options for the treatment of hazardous waste. Hazardous wastes are distinguished from other wastes by their listing in waste statutes and regulations or by exhibiting hazardous properties. In the United States, for example, a waste may be considered hazardous if it is shown to be ignitable, corrosive, reactive or toxic. Mixtures of hazardous wastes with other wastes may also be considered hazardous.

Because of the higher potential hazard of dealing with such wastes and the uncertainty often associated with their composition, special procedures for transportation, handling, storage, monitoring and control are required. Special handling may also be necessary for any residues remaining after treatment.

The most common combustion technology in hazardous waste incineration is the rotary kiln. Facilities in the merchant sector range in size from 82 to 270 tons per day waste throughput (European Commission 2006). Certain hazardous wastes, particularly spent solvents, are also burnt as fuel in cement kilns. This latter application is covered under section V.B. of the present guidelines.

Similar to the incineration of municipal solid waste, hazardous waste incineration offers the benefits of destruction of organic (including toxic) materials, of volume reduction and concentration of pollutants into relatively small quantities of ashes, and, less frequently, energy recovery.

Hazardous waste incinerators have the potential to be significant sources of environmental pollution (see section 2).

Hazardous waste is normally incinerated in two types of facilities:

- Merchant plants, which provide commercial, off-site, waste treatment services. These incinerators handle a variety of waste streams and can compete internationally for business;[1]
- Dedicated or captive hazardous waste incinerators, which are typically located at large industrial facilities and process waste streams generated at the site, for example an incinerator at a chemical manufacturing plant treating chlorinated wastes to recover hydrogen chloride (HCl).

Solid residues from hazardous waste incinerators are similar to those of municipal solid waste incinerators with the exception of slag resulting from rotary kiln incineration.

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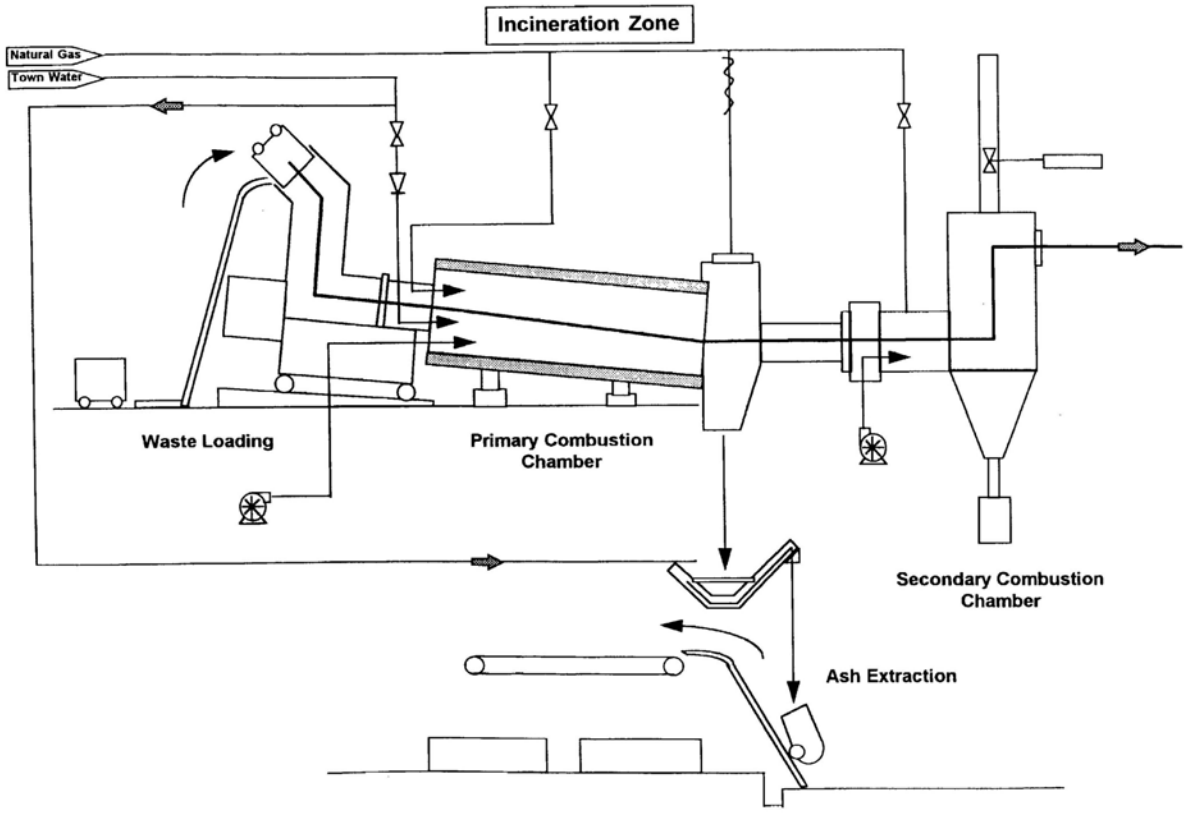
[1] Note the requirements of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal regarding the shipment of hazardous wastes.

2.2.1 Design and operation of hazardous waste incinerators

For the incineration of hazardous waste rotary kilns are most commonly used (Figure 3), but grate incinerators (including co-firing with other wastes) are also sometimes applied to solid wastes, and fluidized bed incinerators to some pretreated materials. Static furnaces are also widely applied at on-site facilities at chemical plants.

Figure 3. Schematic of a rotary kiln incineration system



Due to the hazardous (and often uncertain) composition of the incoming waste streams, there is a greater emphasis on acceptance criteria, storage, handling and pretreatment than with municipal solid waste. For low-energy-value wastes, auxiliary fuels may be required.

In a rotary kiln solid, sludge, containerized or pumpable waste is introduced at the upper end of the inclined drum. Temperatures in the kiln usually range between 850 °C (500 °C when used as a gasifier) and 1,450 °C (as a high-temperature ash melting kiln). The slow rotation of the drum allows a residence time of 30 to 90 minutes. Temperatures in the range of 850 °C – 1,000 °C can be considered adequate for destruction of non-halogenated hazardous waste, while 1,100 °C – 1,200 °C is considered adequate for breaking down halogenated hazardous compounds, i.e. PCDD/PCDF, PCB and HCB.

The secondary combustion chamber following the kiln allows the oxidation of the combustion gases. Liquid wastes or auxiliary fuels may be injected here along with secondary air to maintain a minimum residence time of 2 seconds and temperatures in the range of 850 °C – 1,100 °C, effectively breaking down most remaining organic compounds (requirements for combustion conditions are prescribed e.g. in the EU-Directive 2000/76/EC on the Incineration of Waste).

Hazardous waste is also incinerated in cement kilns. This application is addressed in section V.B of the present guidelines.

2.2.2 Delivery, storage and pretreatment of hazardous waste

Before accepting a hazardous waste for treatment, merchant incinerators must assess and characterize the material. Documentation by the producer is routinely required, including the origin of the waste, its code or other designation, the identification of responsible persons and the presence of particular hazardous materials. The waste must also be properly packaged to avoid the possibility of reaction and emissions during transport.

Storage at the incinerator site will depend on the nature and physical properties of the waste. Solid hazardous waste is typically stored in bunkers constructed to prevent leakage into any environmental media and enclosed to allow the removal of bunker air to the combustion process. Liquid wastes are stored in tank farms, often under inert gas atmosphere (for example N_2), and transported to the incinerator by pipeline. Some wastes may be fed directly to the incinerator in their transport containers. Pumps, pipelines and other equipment that may come into contact with the wastes must be corrosion proof and accessible for cleaning and sampling.

Pretreatment operations may include neutralization, drainage or solidification of the waste. Shredders and mechanical mixers may also be used to process containers or to blend wastes for more efficient combustion.

2.3 Sewage sludge incineration

Domestic sewage sludge is disposed of in a number of ways, including application on agricultural land after pre-treatment, surface disposal (e.g. landscaping), incineration, co-disposal with municipal solid waste and co-incineration. The incineration of sewage sludge is practised in several countries, either alone or through co-incineration in municipal solid waste incinerators or in other combustion plants (e.g. coal-fired power plants, cement kilns). The effective disposal of sewage sludge by this process depends on a number of factors. These include whether the sewage is mixed with industrial waste streams (which can increase heavy metal loadings), location (coastal locations can result in salt water intrusion), pretreatment (or the lack thereof), and weather (rainfall dilution) (European Commission 2006).

The incineration of sewage sludge presents some differences from the incineration of municipal solid waste and hazardous waste. The variability of moisture content, energy value, and possible mixture with other wastes (e.g. industrial waste if sewage systems are interconnected) require special considerations in handling and pretreatment.

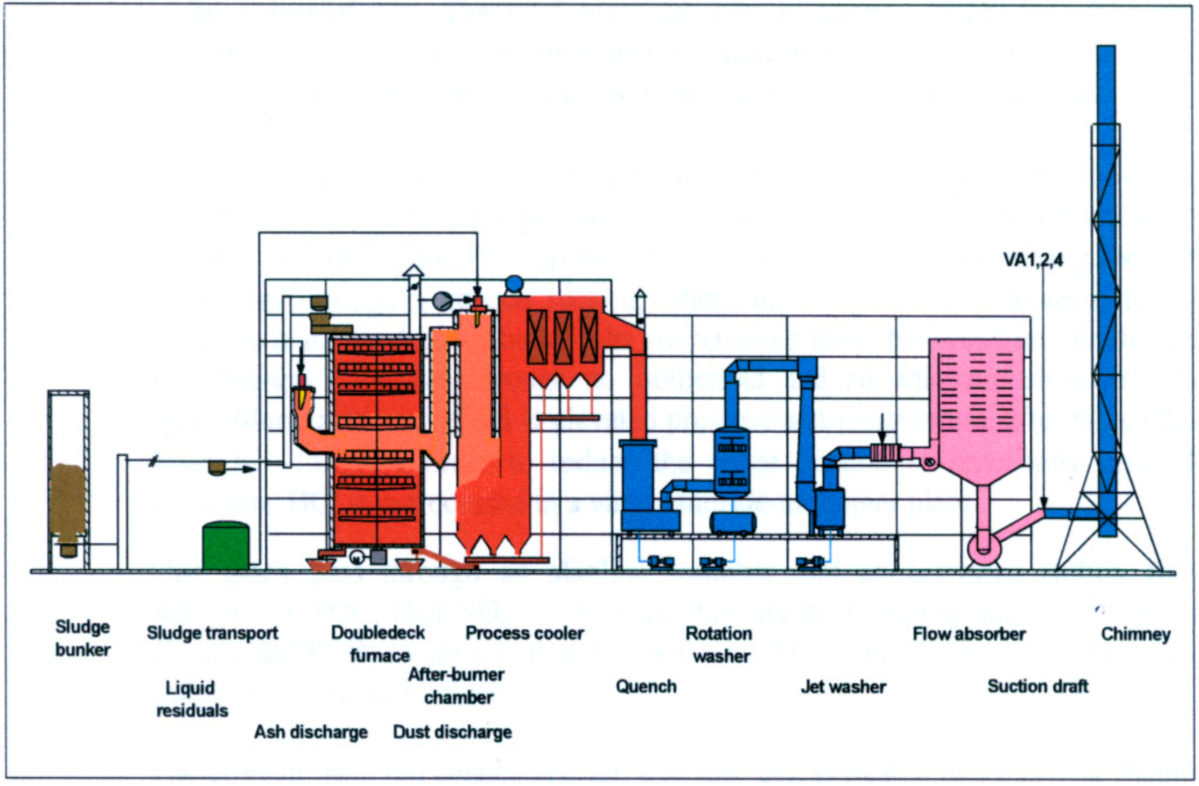
Pretreatment, especially dewatering and drying, is particularly important in preparing sludge for incineration. Drying reduces the volume of the sludge and increases the heat energy of the product. Moisture removal to at least 35% dry solids is normally required to provide the necessary heat energy for autothermal incineration. Further drying may be necessary if co-incineration with municipal solid waste is envisioned.

As with municipal solid waste and hazardous waste incinerators, pollutants and chemicals listed in Annex C and their precursor compounds are available in the inputs to sewage sludge incinerators and have resulted in the formation and release of these substances into air, water and residues/waste (See Section 2). Solid residues from sewage sludge incineration are mainly fly ash and bed ash (from fluidized bed incineration) and residues from flue gas treatment (see description of municipal solid waste incineration).

2.3.1 Design and operation of sewage sludge incinerators

A typical sewage sludge incinerator may process as much as 80,000 tons of sewage sludge (35% dry solids) per year. The incineration technologies of choice for sewage sludge are the multiple hearth (Figure 4) and fluidized bed furnace systems, although rotary kilns are also used in smaller applications.

Figure 4. Example of a multiple hearth sewage sludge incinerator



Source: European Commission 2006

Depending on the percentage of dry solids (dryness), an auxiliary fuel, usually heating oil or natural gas, is provided. The preferred operating temperatures are in the range of 850 °C – 950 °C with a 2-second residence time, although some fluidized bed facilities are able to operate at a temperature as low as 820 °C without deterioration in performance. Operation at or above 980 °C can cause ash to fuse (European Commission 2006).

Sewage sludge is co-incinerated with municipal solid waste in both fluidized bed and mass burn (grated) incinerators. In the latter case, a ratio of 1:3 (sludge to waste) is typical, with dried sludge introduced into the incineration chamber as a dust or drained sludge applied to the grate through sprinklers. In some cases, drained or dried sludge may be mixed with municipal solid waste in the bunker or hopper before being charged to the incinerator. The feeding methods represent a significant proportion of the additional capital investment required for co-incineration.

2.3.2 Pretreatment of sewage sludge

Some pretreatment of sludge may occur before delivery to an incineration facility. This may include screening, anaerobic and aerobic digestion, and the addition of treatment chemicals.

Physical dewatering reduces sludge volume and increases heating value. Mechanical dewatering processes include decanters, centrifuges, belt filter and chamber filter presses. Conditioners (for example, flocking agents) are often added before dewatering to facilitate drainage. Mechanical dewatering can routinely achieve 20–35% dry solids (European Commission 2006).

Drying introduces heat to further dewater and condition the sludge. Heat for drying at the incineration facility is often provided by the incineration process itself. Drying processes can be direct (sludge contacts thermal carrier) or indirect (for example, heat supplied by steam plant). In direct drying the vapour and gas mixture must be subsequently cleaned.

Autothermal (self-sustaining) incineration of sludge requires 35% dry solids. Although mechanical dewatering can reach this threshold, additional drying of sludge to as much as 80–95% dry solids may be employed to increase the heat value. Co-incineration with municipal solid waste generally requires additional sludge drying.

3. Sources of formation of chemicals listed in Annex C

For formation mechanisms of chemicals listed in Annex C of the Stockholm Convention refer to section III.C (i) of the present guidelines.

Chemicals listed in Annex C are released into the air, into water (when wet flue gas cleaning systems are installed or when residues are washed by liquids to remove some toxic substances) and by solid residues.

Solid residues from municipal solid waste incineration are mainly bottom ash, boiler ash and fly ash. Solid residues from hazardous waste incinerators are similar to those of municipal solid waste incinerators with the exception of slag resulting from rotary kiln incineration. Solid residues from sewage sludge incineration are mainly fly ash and bed ash (from fluidized bed incineration) and residues from flue gas treatment (see description of municipal solid waste incineration).

In addition residues arise from flue gas treatment that show different characteristics depending on the systems (dry, semi-wet, wet) installed. When wet systems are applied filter cake from wastewater treatment and gypsum will also accumulate. Furthermore residues from air polishing have to be considered.

Options for treatment of the air polishing residues depend on the adsorbent used (activated carbon, coke, lime, sodium bicarbonate, zeolite). The residue of (activated) carbon from fixed bed reactors is sometimes permitted to be incinerated in the waste incineration plant itself, if certain process conditions are fulfilled. The residue of entrained bed systems can also be incinerated, if the applied adsorbent is activated carbon or oven cokes only. If a mixture of other reagents and activated carbon is used, the residue is generally sent for external treatment or disposal, since there might be risks of corrosion.

In many countries waste fractions generated by waste incineration plants are classified as hazardous waste, with the exception of gypsum from flue gas desulphurization and ferrous and non-ferrous metal scrap. As an example Austrian law requires that if the limit for PCDD/PCDF (100 ng I-TEQ/kg) in the wastes is exceeded, then the wastes must be disposed of in an environmentally sound manner. This means in most cases landfilling in specially engineered landfills (following pretreatment) or underground storage. Furthermore, according to Austrian law, formation and dispersion of dust from these wastes must be prevented during transport and intermediate storage (Austrian Waste Incineration Ordinance, Fed. Law Gazette Nr. II 389/2002).

Table 1 illustrates the relative solid residue masses for a typical municipal solid waste incinerator.

Table 1. Waste and solid residues from municipal solid waste incineration

Types of waste	Specific mass, dry (kg/t of waste)
Slag/ash (including grate siftings/riddlings)	200–350
Dust from boiler and dedusting	20–40
Residues from flue gas cleaning without filter dust:	
Wet sorption[a]	8–15
Semi-wet sorption	15–35
Dry sorption	7–45
Residues from flue gas cleaning and filter dust:	
Wet sorption[a]	30–50
Semi-wet sorption	40–65
Dry sorption	32–80
Loaded activated carbon	0.5–1

a. Wet sorption residues have a specific dryness (e.g. 40–50% dry solids) (74, TWG Comments, 2004).

Source: Umweltbundesamt Deutschland 2001

Typical concentrations of organic compounds in ashes from modern waste incineration plants are given in Table 2.

Table 2. Concentration ranges of organic compounds in ashes from modern facilities

Parameter	Bottom ash (ng/kg)	Boiler ash (ng/kg)	Fly ash (ng/kg)
PCDD/PCDF (I-TEQ)	< 1–10	20–500	200–10,000
PCB	< 0.005–0.05	0.004–0.05	10,000–250,000
PCBz[a]	< 0.002–0.05	200,000–1,000,000	100,000–4,000,000
PCPh[b]	< 0.002–0.05	20,000–500,000	50,000–10,000,000
PAH[c]	< 0.005–0.01	10,000–300,000	50,000–2,000,000

a. PCBz: polychlorinated benzenes.

b. PCPh: polychlorinated phenols.

c. PAH: polycyclic aromatic hydrocarbons.

Source: European Commission 2006.

Emissions to air from waste incineration plants depend to a large extent on the firing conditions and the design and operating conditions of the flue gas treatment systems. PCDD/PCDF emissions from most modern waste incineration plants using best available techniques are in the range of 0.0008–0.05 ng I-TEQ/Nm^3; (see Stubenvoll, Böhmer et al. 2002). However, emissions can be higher than 150 ng I-TEQ/Nm^3 in the case of badly designed and operated plants.

PCDD/PCDF emissions to water only occur where wet systems are applied for flue gas treatment. Modern wastewater treatment plants include steps such as neutralization, precipitation, flocculation and activated coke filters to remove organic substances. Generally emissions from these plants are in the range of 0.01–0.3 ng I-TEQ/l (e.g. in the Waste Incineration Directive of the European Council, an PCDD/PCDF emission limit value (ELV) of 0.3 ng I-TEQ/l is prescribed).

Typical concentrations of PCDD/PCDF found in the waste itself are reported to be in the range of 50–250 ng I-TEQ/kg for municipal solid waste, up to 10,000 ng I-TEQ/kg for hazardous waste and 8.5–73 ng I-TEQ /kg for sewage sludge (European Commission 2006).

Table 3 gives an estimation of PCDD/PCDF (I-TEQ) releases into different media based on typical parameters of municipal solid waste incinerators designed and operated according to best available techniques (for parameters see Stubenvoll, Böhmer et al. 2002 and European Commission 2006).

Table 3. Estimation of releases of PCDD/PCDF into different media from municipal waste incinerators

Medium	Accumulation per t of treated waste	Unit	Average concentration	Unit	Specific release (µg I-TEQ/t waste)
Bottom ash	220	kg	46	ng I-TEQ/kg	10.12
Fly ash	20	kg	2,950	ng I-TEQ/kg	59
Filter cake	1	kg	4,000	ng I-TEQ/kg	4
Wastewater	450	l	0.3	ng I-TEQ/l	0.135
Air	5,000	Nm^3	0.02	ng I-TEQ/Nm^3	0.1
Total release					**73.355**

Source: Stubenvoll, Böhmer et al. 2002 and European Commission 2006

From the data presented in Table 3 it becomes clear that dioxins and furans are mainly released by solid waste from incineration. Filter cake (e.g. by underground storage) and fly ash have to be disposed of in dedicated landfills in most countries (sometimes after pretreatment) whereas bottom ash is used in some countries (e.g. for road construction), usually after pretreatment.

Provided that the total content and the leaching rate of persistent organic pollutants from ashes and other wastes from waste incineration is low (this can be achieved e.g. by pretreatment) the specially engineered landfills – if designed and operated according to best available techniques – can be regarded as final sinks for hazardous substances, so that the risk of further release of and re-exposure to these chemicals is strongly reduced. In this case emissions from modern waste incineration plants are very low.

4. Alternatives to the incineration of municipal solid waste, hazardous waste and sewage sludge

For an overview of waste management considerations see section III.C (ii) of the present guidelines.

In addition to urging Parties to give priority to approaches that promote recycling and recovery of waste and minimize waste generation, the Stockholm Convention stresses the importance of considering alternative disposal and treatment options that may avoid the formation and release of chemicals listed in Annex C. Examples of such alternatives, including emerging technologies, are listed below.

For municipal waste, possible alternatives to incineration are:

- Zero waste management strategies, which aim to eliminate the generation of waste through the application of a variety of measures, including legislative and economic instruments;
- Waste minimization, source separation and recycling to reduce the waste volume requiring final disposal;
- Composting, which reduces waste volume by biological decomposition;
- Mechanical biological treatment, which reduces waste volume by mechanical and biological means and generates residues requiring further management;

- High-temperature melting, which uses thermal means to reduce waste volume and encapsulates residues requiring further management.
- Specially engineered landfill, which contains and isolates wastes (including effective capturing and burning of formed methane with energy recovery or at least flaring if the latter technique is not applicable);

For hazardous waste, possible alternatives to incineration include:

- Waste minimization and source separation with final disposal by other techniques or to appropriate landfill;

For POPs wastes, possible alternatives to incineration are listed in the Basel Technical Guidelines (Basel Convention Technical Guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants (POPs); 2005)

- Gas phase chemical reduction;
- Base catalysed decomposition;
- Sodium reduction;
- Supercritical water oxidation.

For non-contaminated sewage sludge, possible alternatives to incineration are disposal to landfill or landspreading, which avoid formation of chemicals listed in Annex C. Though it is noted that any persistent organic pollutants and other hazardous substances present in such sludges may be released to the environment through this latter approach. For land application, non-contaminated sludge should ideally be collected separately.

Further work is needed by the international community to test and verify technologies such as those listed above. Work is also needed to promote additional innovation in this important field.

5. Best environmental practices for waste incineration

Well-maintained facilities, well-trained operators, a well-informed public, and constant attention to the process are all important factors in minimizing the formation and release of chemicals listed in Annex C from the incineration of waste. In addition, effective waste management strategies (for example, waste minimization, source separation and recycling), by altering the volume and character of the incoming waste, can also significantly impact releases.

It should be mentioned here that due to the unclear definition of what constitutes best environmental practices there is some overlap between the descriptions of best environmental practices and best available techniques. Some practices listed in this subsection on best environmental practices may also be a prerequisite for operation of a plant using best available techniques.

In this subsection best environmental practices for operation of a waste incinerator are described. Relevant practices that should be applied before the waste reaches the incineration plants are described elsewhere in this document (see for example section III.C on cross-cutting considerations).

5.1 Waste management practices

Waste management considerations, which are described in section III.C (ii) of the present guidelines, and the alternative approaches outlined in subsection 6 below, must be taken into account as part of overall waste prevention and control strategies.

5.1.1 Waste minimization

Reducing the overall mass of wastes that have to be disposed of by any means serves to reduce both the releases and residues from incinerators. Diversion of biodegradables to composting and initiatives to reduce the amount of packaging materials entering the waste stream can significantly affect waste volumes. Responsibility for waste minimization lies only to a minor extent with the operator of a waste incineration plant. However, coordination and harmonization of relevant activities on different organizational levels (e.g. operator, local, regional or national level) is of major importance for protection of the environment as a whole.

5.1.2 Source separation and recycling

Kerbside or centralized sorting and collection of recyclable materials (for example, aluminium and other metals, glass, paper, recyclable plastics, and construction and demolition waste) also reduces waste volume, saves valuable resources and removes some non-combustibles. Responsibility for these activities must be coordinated between relevant levels.

5.1.3 Waste inspection and characterization

A thorough knowledge of the characteristics and attributes of the incoming waste is essential. The characteristics of a particular waste stream may vary significantly from country to country and region to region. If certain wastes or waste constituents are considered inappropriate for incineration, procedures should be in place for detecting and separating these materials in the waste stream or residues. Checking, sampling and analyses should be performed. This is particularly true for hazardous wastes. Manifests and audit trails are important to maintain and they should be kept updated. Table 4 illustrates some of the techniques applicable to the different types of waste.

Table 4. Examples of inspection techniques

Waste type	Techniques	Comments
Mixed municipal wastes	Visual inspection in bunker Spot checking of individual deliveries by separate offloading Weighing the waste as delivered Radioactive detection	Industrial and commercial loads may have elevated risks
Pretreated municipal wastes and refuse-derived fuels	Visual inspection Periodic sampling and analysis for key properties or substances	
Hazardous wastes	Visual inspection Sampling/analysis of all bulk tankers Random checking of drummed loads Unpacking and checking of packaged loads Assessment of combustion parameters Blending tests on liquid wastes prior to storage Control of flashpoint for wastes in the bunker Screening of waste input for elemental composition, for example by EDXRF[a]	Extensive and effective procedures are particularly important for this sector. Plants receiving monostreams may be able to adopt more simplified procedures
Sewage sludges	Periodic sampling and analysis for key properties and substances Checking for stones/metals prior to drying stages Process control to adapt to sludge variation	

a. EDXRF: energy dispersive X-ray fluorescence (spectrometer).
Source: European Commission 2006

5.1.4 Removal of non-combustibles at the incinerator

The removal of both ferrous and non-ferrous metals on site is a common practice at municipal solid waste incinerators.

5.1.5 Proper handling, storage and pre-treatment

Proper handling, particularly of hazardous waste, is essential. Appropriate sorting and segregation should be undertaken to enable safe processing (Table 5).

Storage areas must be properly sealed with controlled drainage and weatherproofing. Fire detection and control systems for these areas should also be considered along with adequate capacity to retain contaminated fire water onsite. Storage and handling areas should be designed to prevent contamination of environmental media and to facilitate clean-up in the event of spills or leakage. Odours and release of volatile persistent organic pollutants to environmental media can be minimized by using bunker air for the combustion process. In the case of sewage sludge, pre-treatment must ensure that adequate drying and conditioning has been performed.

Table 5. Examples of segregation techniques

Waste type	Segregation techniques
Mixed municipal wastes	Segregation is not routinely applied unless various distinct waste streams are received, when these can be mixed in the bunker Bulky items requiring pretreatment can be segregated Emergency segregation areas for rejected waste
Pretreated municipal wastes and refuse-derived fuels	Segregation not routinely applied Emergency segregation areas for rejected waste
Hazardous wastes	Extensive procedures required to separate chemically incompatible materials (examples given as follows): Water from phosphides Water from isocyanates Water from alkaline materials Cyanide from acids Flammable materials from oxidizing agents Maintain separation of presegregated packed delivered wastes
Sewage sludges	Wastes generally well mixed before delivery to plant Some industrial streams may be separately delivered and require segregation for blending

Source: European Commission 2006

5.1.6 Minimizing storage times

Although having a constant supply of waste is important for continuous operation and stable firing conditions in large municipal solid waste incinerators, stored wastes are unlikely to improve with age. Minimizing the storage period will help prevent putrefaction and unwanted reactions, and the deterioration of containers and labelling. Managing deliveries and communicating with suppliers will help ensure that reasonable storage times (e.g. four to seven days for municipal solid waste) are not exceeded.

5.1.7 Establishing quality requirements for waste-fed facilities

Operators must be able to accurately predict the heating value and other attributes of the waste being combusted in order to ensure that the design parameters of the incinerator are being met. This can be done using the results from a feed monitoring programme of key contaminants and parameters where sampling and analysis frequencies and rigour would increase as feed variability increases.

5.1.8 Waste loading

For facilities that accept heterogeneous municipal solid waste, proper mixing and loading of the feed hopper is critical. Loading crane operators must have both the experience and the appropriate vantage point to be able to select the appropriate mix of waste types to keep the incinerator performing at peak efficiency.

5.2 Incinerator operating and management practices

5.2.1 Ensuring good combustion

To achieve optimal prevention of formation, and capture, of chemicals listed in Annex C, proper care and control of both burn and exhaust parameters are necessary. In continuous feed units, the timing of waste introduction, control of burn conditions and post-burn management are important considerations (see subsection 6 below).

5.2.2 Avoiding cold starts, upsets and shutdowns

These events are normally characterized by poor combustion, and consequently create the conditions for formation of chemicals listed in Annex C. For smaller, modular incinerators operating in batch mode, start-up and shutdown may be daily occurrences. Preheating the incinerator and initial co-firing with a clean fossil fuel will allow efficient combustion temperatures to be reached more quickly. Wherever possible, however, continuous operation should be the practice of choice. Independent of the operation mode waste should be fed into the combustion system only when the required temperature (e.g. above 850 °C) is reached. Upsets can be minimised through periodic inspection and preventive maintenance. Incinerator operators should not feed the waste during filter bypass (“dump stack”) operations or during severe combustion upsets.

5.2.3 Regular facility inspections and maintenance

Routine inspections by the operator and periodic inspections by the relevant authority of the furnace and air pollution control devices should be conducted to ensure system integrity and the proper performance of the incinerator and its components.

5.2.4 Monitoring

High-efficiency combustion is facilitated by establishing a monitoring regime of key operating parameters, such as carbon monoxide (CO), volumetric flow rate, temperature and oxygen content. Low CO is associated with higher combustion efficiency in terms of the burnout of the municipal solid waste. Generally, if the CO concentration is low by volume (for example, < 50 parts per million or 30 mg/m^3) in the stack flue gases, this provides a general indication that high combustion efficiency is being maintained within the combustion chamber. Good combustion efficiency is related to the minimization of the formation of PCDD/PCDF within the incinerator, and the combustion temperature in the chamber should therefore be recorded.

Carbon monoxide, oxygen in the flue gas, particulate matter, hydrogen chloride (HCl), sulphur dioxide (SO_2), nitrogen oxides (NO_x), hydrogen fluoride (HF), airflows and temperatures, pressure drops, and pH in the flue gas should all be routinely monitored. These measurements reflect combustion conditions and give a general indication of the potential for formation and release of chemicals listed in Annex C. Periodic or semi-continuous measurement (continuous sampling and periodic analysis) of PCDD/PCDF in the flue gas can help the operator to ensure that releases are minimized and the incinerator is operating properly.

In Japan, simplified measurement methods by bioassay are approved as official standard methods for periodical measuring of dioxins from waste incineration plants with capacity less than 2 tons/hour (see also section III.C (vi))

5.2.5 Handling of residues

Bottom and fly ash from the incinerator must be handled, transported and disposed of in an environmentally sound manner. This includes the separate management of bottom ash from fly ash and other flue gas treatment residues in order to avoid contamination of the bottom ash and thereby improve the potential for bottom ash recovery. Covered hauling and dedicated landfills are a common practice for managing these residues.

Particularly if reuse of the residues is contemplated, an evaluation of the content and potential environmental mobility of heavy metals and chemicals listed in Annex C is required, and guidelines adopted by the Basel Convention and subsequently adopted by the Conference of the Parties of the Stockholm Convention should be followed. Periodic analysis of the ash can also serve as an indicator of incinerator performance or the introduction of non-permitted wastes.

Scrubber effluents, including the filter cake from wet flue gas cleaning, is regarded as hazardous waste in many countries and must be treated and disposed of in an environmentally sound manner (e.g. stabilisation prior to disposal in specially engineered landfills).

5.2.6 Operator training

Regular training of personnel is essential for good operation of waste incinerators. In the United States, for example, training and certification of operators is provided by the American Society of Mechanical Engineers (see also section III.C (v) of the present guidelines).

5.2.7 Maintaining public awareness and communication

Creating and maintaining public goodwill towards a waste incineration project is critical to the success of the venture. Outreach should begin as early in the planning of the project as possible. The public and citizens' advocacy groups will have understandable concerns about the construction and operation of a facility and dealing with these openly and honestly will help prevent misinformation and misunderstanding.

Effective practices for improving public awareness and involvement include: placing advance notices in newspapers; distributing information to area households; soliciting comment on design and operational options; providing information displays in public spaces; maintaining pollutant release and transfer registers; and holding frequent public meetings and discussion forums.

Authorities and proposers of incineration projects should engage with all stakeholders including the public interest groups by: holding regular consultation meetings with concerned citizens; providing days for public visitation; posting release and operational data to the Internet; and displaying real-time data on operations and releases at the facility site. Consultations with the public must be transparent, meaningful and sincere if they are to be effective.

6. Best available techniques for incineration

In addition to applying best environmental practices to the incineration of municipal solid waste, hazardous waste and sewage sludge, there is a variety of demonstrated combustion engineering, flue gas cleaning and residue management techniques that are available for preventing the formation or minimizing the releases of chemicals listed in Annex C. For a detailed analysis of what represents best available techniques for waste incineration reference should be made to the European Commission BAT Reference (BREF) Document on waste incineration (European Commission 2006).

There are also non-incineration and emerging technology options (see section III.C (ii) of the present guidelines) that may represent feasible and environmentally sound alternatives to incineration. The purpose of this subsection, however, is to identify the best techniques applicable to the process of incineration. Best available techniques for incineration include the design, operation and maintenance of a waste incineration plant that effectively minimizes the formation and release of chemicals listed in Annex C.

When considering the best available techniques described here for waste incineration, it is important to consider that the optimal solution for a particular type of incineration installation varies according to local conditions. The best available techniques provided here are not intended as a checklist indicating the best local solution, as this would require the consideration of local conditions to a degree that cannot be described in a document dealing with best available techniques in general.

Hence, the simple combination of the individual elements described here as best available techniques, without consideration of local conditions, is not likely to give the optimized local solution in relation to the environment as a whole (European Commission 2006).

With a suitable combination of primary and secondary measures, PCDD/PCDF performance levels in air emissions no higher than 0.1 ng I-TEQ/Nm^3 (at 11% O_2) are associated with best available techniques. It is further noted that under normal operating conditions emissions lower than this level can be achieved with a well designed waste incineration plant.

Best available techniques for discharges of waste water from effluent treatment plants, receiving flue gas treatment scrubber effluent, are associated with PCDD/PCDF concentration levels of well below 0.1 ng I-TEQ/l.

As an illustrative example of a multimedia guideline, Japan established in 1997 a future target for the total amount of PCDD/PCDF released, including not only PCDD/PCDF contained in emission gas but also those contained in bottom ash and fly ash, of 5 μg I-TEQ/ton-waste (see subsection 3, Table 3 above for comparison).

It should be mentioned that most of the conclusions on best available techniques drawn in this section are taken from the European Commission BREF Document on waste incineration (European Commission 2006). There are many waste incinerator plants worldwide that are designed and operated according to most of the parameters defining best available techniques and that meet the associated emission levels.

6.1 Site selection

For waste incineration, the local factors to be taken into account may, amongst others, include:

- Local environmental drivers, for example background environmental quality may influence the required local performance in respect of releases from the installation, or availability of certain resources;
- The particular nature of the waste(s) that arise locally and the impact of the waste management infrastructure upon the type and nature of waste arriving at the installation;
- The cost and technical possibility of implementing a particular technique in relation to its potential advantages – this is of particular relevance when considering the performance of existing installations;
- The availability, degree of utilization and price of options for the recovery and disposal of residues produced at the installation;
- The availability of users and price received for recovered energy;
- Local economic, market and political factors that may influence the tolerability of the higher gate fees that may accompany the addition of certain technological options.

6.2 Best available techniques for waste input and control

- Maintain the site in a generally tidy and clean state;
- Establish and maintain quality controls over the waste input, according to the types of waste that may be received at the installation. This includes:
  - Establish process input limitations and identify key risks;
  - Communicate with waste suppliers to improve incoming waste quality control;
  - Control waste feed quality on the incinerator site;
  - Check, sample and test incoming wastes;
  - Employ detectors for radioactive materials.

6.3 Best available techniques for combustion

Optimal burn conditions involve:

- Mixing of fuel and air to minimize the existence of long-lived, fuel-rich pockets of combustion products;
- Attainment of sufficiently high temperatures in the presence of oxygen for the destruction of hydrocarbon species;
- Prevention of quench zones or low-temperature pathways that will allow partially reacted fuel to exit the combustion chamber.

Proper management of time, temperature and turbulence (the “3 Ts”), as well as oxygen (airflow), by means of incinerator design and operation will help to ensure the above conditions. Temperatures at or above 850 °C (e. g. for waste with content of halogenated organic substances, expressed as chlorine, > 1% above 1,100 °C) are required for complete combustion in most technologies. Turbulence, through the mixing of fuel and air, helps prevent cold spots in the burn chamber and the build-up of carbon, which can reduce combustion efficiency. The recommended residence time in the secondary combustion chamber in the primary furnace is at least 2 seconds at 6% oxygen.

6.3.1 General combustion techniques

- Ensure design of furnace is appropriately matched to characteristics of the waste to be processed.
- Maintain temperatures in the gas phase combustion zones in the optimal range for completing oxidation of the waste (for example, 850 °C – 950 °C in grated municipal solid waste incinerators, 1,100 °C – 1,200 °C when chlorine content of waste is high).
- Provide for sufficient residence time (e.g. at least 2 seconds at 6% oxygen) and turbulent mixing in the combustion chamber(s) to complete incineration.
- Preheat primary and secondary air to assist combustion.
- Use continuous rather than batch processing wherever possible to minimize start-up and shutdown releases.
- Establish systems to monitor critical combustion parameters such as temperature, pressure drop, levels of CO, CO_2 and O_2 and, where applicable, grate speed.
- Provide for control interventions to adjust waste feed, grate speed, and temperature, volume and distribution of primary and secondary air.
- Install automatic auxiliary burners to maintain optimal temperatures in the combustion chamber(s).
- Use air from bunker and storage facilities as combustion air.
- Install system that automatically stops waste feeding when combustion parameters are not appropriate.

6.3.2 Municipal solid waste incineration techniques

- Mass burn (moving grate) incinerators are well demonstrated in the combustion of heterogeneous municipal solid waste and have a long operational history.
- Water-cooled grated incinerators have the added advantages of better combustion control and the ability to process municipal solid waste with higher heat content.
- Rotary kilns with grates can accept heterogeneous municipal solid waste but a lower throughput than the mass burn or moving grate furnaces.

- Static grated furnaces with transport systems (for example, rams) have fewer moving parts but waste may require more pretreatment (i.e., shredding, separation).
- Modular designs with secondary combustion chambers are well demonstrated for smaller applications. Depending on size, some of these units may require batch operation.
- Fluidized bed furnaces and spreader/stoker furnaces are well demonstrated for finely divided, consistent wastes such as refuse-derived fuel.

6.3.3 Hazardous waste incineration techniques

- Rotary kilns are well demonstrated for the incineration of hazardous waste and can accept liquids and pastes as well as solids.
- Water-cooled kilns can be operated at higher temperatures and allow acceptance of wastes with higher energy values.
- The applicability of waste heat recovery boilers should be considered carefully, particularly with regard to the possibility of PCDD/PCDF reformation.
- Waste consistency (and combustion) can be improved by shredding drums and other packaged hazardous wastes.
- A feed equalization system (for example, screw conveyors that can crush and provide a constant amount of solid hazardous waste to the furnace) will help ensure a continuous, controlled feed to the kiln and maintenance of uniform combustion conditions.

6.3.4 Sewage sludge incineration techniques

- Fluidized bed incinerators are well demonstrated for thermal treatment of sewage sludge.
- Circulating fluid bed furnaces allow greater fuel flexibility than bubbling beds, but require cyclones to conserve bed material.
- Care must be exercised with bubbling bed units to avoid clogging.
- The use of heat recovered from the process to aid sludge drying will reduce the need for auxiliary fuel.
- Supply technologies are important in the co-incineration of sewage sludge in municipal solid waste incinerators. Demonstrated techniques include: dried sludge blown in as dust; drained sludge supplied through sprinklers and distributed and mixed on the grate; and drained or dried sludge mixed with municipal solid waste and fed together (European Commission 2006).[2]

6.4 Best available techniques for flue gas treatment

The type and order of treatment processes applied to the flue gases once they leave the incineration chamber is important, both for optimal operation of the devices and for the overall cost-effectiveness of the installation. Waste incineration parameters that affect the selection of techniques include: waste type, composition, and variability; type of combustion process; flue gas flow and temperature; and the need for, and availability of, wastewater treatment. The following treatment techniques have direct or indirect impacts on preventing the formation and minimizing the release of chemicals listed in Annex C. Best available techniques involve applying the most suitable combination of flue gas cleaning systems.

6.4.1 Dust (particulate matter) removal techniques

- Dust removal from the flue gases is essential for all incinerator operations.

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[2] Additional information on the comparison of combustion techniques among furnace types may be found in Annex I.

- Electrostatic precipitators and fabric filters have demonstrated effectiveness as capture techniques for particulate matter in incinerator flue gases. For a comparison of the primary dust removal systems see Table 3 in section III.C (iv) of the present guidelines.
- Cyclones and multicyclones are less efficient in dust removal and should only be used in a pre-dedusting step to remove coarser particles from the flue gases and reduce dust loads on downstream treatment devices. Preseparation of coarse particles will decrease the amount of fly ash contaminated with high loads of persistent organic pollutants.
- The collection efficiency of electrostatic precipitators is reduced as electrical resistivity of the dust increases. This may be a consideration in situations where waste composition varies rapidly (e.g. hazardous waste incinerators).
- Electrostatic precipitators and fabric filters should be operated below 200 °C to minimize formation of PCDD/PCDF and other chemicals listed in Annex C.
- Wet electrostatic precipitators can capture very small particle sizes but require effluent treatment and are usually employed following dedusting.
- Fabric filters (bag filters) are widely applied in waste incineration and have the added advantage, when coupled with semi-dry sorbent injection (spray drying), of providing additional filtration and reactive surface on the filter cake.
- Pressure drop across fabric filters and flue gas temperature (if a scrubbing system is used upstream) should be monitored to ensure filter cake is in place and bags are not leaking or being wetted. A bag leak detection system using a triboelectric detector represents one option for monitoring fabric filter performance.
- Fabric filters are subject to water damage and corrosion and gas streams must be maintained above the dew point (130 °C – 140 °C) to prevent these effects. Some filter materials are more resistant to damage. For an outline of filter material choices and attributes see Table 2 in section III.C (iv) of the present guidelines.

6.4.2 Acid gas removal techniques

- Wet scrubbers have the highest removal efficiencies for soluble acid gases among the demonstrated techniques where pH of scrubber water is a function of removal efficiency. Solid particles in scrubber water may also cause interaction with PCDD/PCDF in the mobile gas stream, thus influencing the reliability of the relationship between results obtained from periodic stack gas monitoring and plant destruction performance.
- Pre-dedusting of the gas stream may be necessary to prevent clogging of the scrubber, unless scrubber capacity is sufficiently large.
- The use of carbon-impregnated materials, activated carbon, or coke in scrubber packing materials can achieve a 70% reduction in PCDD/PCDF across the scrubber (European Commission 2006) but this may not be reflected in overall releases.
- Spray dryers (semi-wet scrubbing) also provide high removal efficiencies and have the advantage of not requiring subsequent effluent treatment. In addition to the alkaline reagents added for acid gas removal, activated carbon injection is also effective in removing PCDD/PCDF as well as mercury. Spray dry scrubbing systems also typically achieve 93% SO_2 and 98% HCl control.
- Spray dryers, as noted above, are often deployed upstream of fabric filters. The filters provide for capture of the reagents and reaction products as well as offering an additional reactive surface on the filter cake.
- Inlet temperature to the fabric filter in such combinations is important. Temperatures above 130 °C – 140 °C are normally required to prevent condensation and corrosion of the bags.

- With regards to acid gas removal, dry scrubbing systems cannot reach the efficiency of wet or semi-wet (spray dry) scrubbers without significantly increasing the amount of reagent/sorbent. Increased reagent use adds to the volume of fly ash.

6.4.3 Flue gas polishing techniques

- Additional dust removal may be appropriate before cleaned flue gases are sent to the stack. Techniques for the polishing of flue gas include fabric filters, wet electrostatic precipitators and venturi scrubbers.
- Double filtration (filters in series) can routinely achieve collection efficiencies for dust at or below 1 mg/m^3.
- The additional benefits of these techniques may be small, and the cost-effectiveness disproportionate, if effective upstream techniques are already being applied.
- Flue gas polishing may have greatest utility at large installations and in further cleaning of gas streams prior to selective catalytic reactions.
- Adsorption can be achieved by activated carbon injection, in static beds or by use of carbon impregnated materials.

6.4.4 Nitrogen oxides (NO_x) removal techniques using a catalyst

- Although the primary role of selective catalytic reaction is to reduce NO_x emissions, this technique can also destroy gas phase chemicals listed in Annex C (for example, PCDD/PCDF) with an efficiency of 98–99.5% (European Commission 2006).
- Flue gases may have to be reheated to the 250 °C – 400 °C required for proper operation of the catalyst.
- Performance of selective catalytic reaction systems improves with upstream flue gas polishing. These systems are installed after dedusting and acid gas removal.
- The significant cost (capital and energy) of selective catalytic reaction is more easily borne by large facilities with higher gas flow rates and economies of scale.

6.5 Management techniques for solid residues

Wastes and residues from incineration include various types of ash (e.g. bottom ash, boiler ash, fly ash) and residues from other flue gas treatment processes (such as gypsum from wet scrubbers), including liquid effluents in the case of wet scrubbing systems.

Dry and semi-wet scrubbers generally produce greater amounts of solid waste than wet scrubbers. Furthermore this waste can contain fly ash (if it is not separated efficiently), heavy metals (especially mercury) and unreacted sorbent.

Because constituents of concern may vary considerably, maintaining the separation of residues for treatment, management and disposal is in general appropriate. The presence and concentration of chemicals listed in Annex C in these residues (if separately treated) is a function of their presence in the incoming waste, survival or formation in the incineration process, and formation and capture during flue gas treatment. Techniques that may be considered are listed in detail in the Basel Technical Guidelines, chapter IV, G 3, and also in section III.C (iv) - subsections 2.1.2 and 2.2 of the present guidelines. It will be necessary to establish case by case, which of these techniques may be considered as best available techniques and best environmental practices.

6.5.1 Bottom and boiler ash treatment techniques

Bottom ash from incinerators designed and operated according to best available techniques (i.e., incinerators showing a good burnout behaviour) tends to have a very low content of chemicals listed in Annex C, in the same order of magnitude as background concentrations in urban soils (i.e., < 1–10 ng I-TEQ /kg ash). Boiler ash levels tend to be higher (20–500 ng I-TEQ /kg ash) but both are well below the average concentrations found in fly ash (European Commission 2006).

Because of the differences in pollutant concentration, the mixing of bottom ash with fly ash will contaminate the former and is forbidden in many countries. Separate collection and storage of these residues provides operators with more options for disposal.

Bottom ash (or slag from fluidized bed incinerators) is disposed of in landfills in many countries but may be reused in construction and road-building material following pretreatment. Prior to such use, however, an assessment of content and leachability should be conducted and upper levels of persistent organic pollutants, heavy metals and other parameters have to be defined.

Pretreatment techniques include dry, wet and thermal treatment as well as screening and crushing and separation of metals.

Leachability of chemicals listed in Annex C is known to increase with increasing pH and humic (presence of organic matter) conditions. This would suggest that disposal in lined and dedicated landfills is preferable to mixed waste facilities.

6.5.2 Management techniques for flue gas treatment residues

Unlike bottom ash, air pollution control device residuals, including fly ash and scrubber sludges, contain relatively high concentrations of heavy metals, organic pollutants (including PCDD/PCDF), chlorides and sulphides. Separate removal of fly ash and residues from flue gas cleaning stages (e.g. those for acid gas and dioxin removal) prevents mixing of low contaminated waste fractions with highly contaminated ones.

Whenever bottom ash is to be further used (e.g. as construction material) mixing with other flue gas treatment residues is not a best available technique.

Fly ash is disposed of in dedicated landfills in many countries. However, pre-treatment is likely to be required for this to constitute BAT. (see also section III.C (iv) - subsections 2.1.2 and 2.2).

6.6 Best available techniques for effluent treatment

Process wastewater in incineration arises mainly from the use of wet scrubbing technologies. The need for and treatment of wastewater can be alleviated by the use of dry and semi-wet systems.

Best available techniques for wastewater treatment include optimization of the recirculation and reuse of wastewater arising on the site within the installation, the use of separate systems for the treatment of wastewater with different level of contamination, use of physico-chemical treatment of the scrubber effluents and removal of ammonia if necessary. For the removal of organic compounds activated coke filters and carbon-impregnated polymers are used.

With a combination of suitable treatment techniques (see also section III.C Cross-cutting considerations) PCDD/PCDF levels in the treated wastewater will be in the range of < 0.01–0.1 ng I-TEQ/l (European Commission 2006).

6.7 Impact of best available techniques and best environmental practices on other pollutants

The description of techniques and practices in this provisional guidance is primarily focused on their demonstrated effectiveness in the prevention, minimization or reduction of the formation and release of chemicals listed in Annex C. Many of these practices also serve to reduce releases of other pollutants, and some may be primarily designed for this purpose (e.g. source separation of metals and other non-combustibles from waste streams, selective catalytic reduction for NO_x control, acid gas controls for reducing SO_2, carbon adsorption for mercury control). Some that may have been designed for the capture of other pollutants (e.g. higher inlet temperature electrostatic precipitators) have had to be redesigned or replaced to avoid increasing formation and release of chemicals listed in Annex C.

In the final analysis, what constitutes best available techniques and best environmental practices for waste incineration is broader than the impact on chemicals listed in Annex C alone, involving all aspects of the incineration, energy recovery, flue gas treatment, wastewater treatment and residue treatment process. The great majority of these, however, are complementary with the aims of preventing or reducing releases of the chemicals listed in Annex C (for consideration of co-benefits see section III.C (iii) of the present guidelines).

6.8 New and significantly modified incinerators

The Stockholm Convention (Annex C, Part V, section B, subparagraph (b)) states that before Parties proceed with proposals to construct or significantly modify sources that release chemicals listed in Annex C, they should give "priority consideration" to "alternative processes, techniques or practices that have similar usefulness but which avoid the formation and release" of these compounds. In cases where such consideration results in a determination to proceed with construction or modification, the Convention provides a set of general reduction measures for consideration. While these general measures have been incorporated into the preceding discussion of best available techniques and best environmental practices for these categories, there are additional factors that will be important in deciding whether it is feasible to construct or modify a waste incinerator. The direct and indirect effects on human health and the environment should be addressed by performing an appropriate environmental impact assessment. Additional factors are listed below:

6.8.1 Additional factors in the siting of new municipal solid waste incinerators

- Is there an accurate prediction of the nature and volume of non-recyclable municipal solid waste generation in the area to be served?
- Will the supply allow for continuous operation of the incinerator?
- Does this prediction include appropriate waste minimization, recycling and recovery programmes?
- Is the transportation infrastructure sufficient to support collection and hauling?
- Has the likelihood of intra- or inter-State restrictions on waste transportation been investigated?
- Are there available markets for any on-site separated materials?
- Are there available markets for excess steam or electricity generated on site?
- Are there environmentally sound options for the treatment and disposal of residues?

6.8.2 Additional factors in the siting of new hazardous waste incinerators

- Is there an accurate prediction of the nature and volume of hazardous waste generation in the area to be served?
- Will the supply allow for continuous operation of the incinerator?
- Is the infrastructure sufficient to support transportation needs?
- If international transport is envisioned, are the necessary agreements in place to allow transfer across borders?
- Have the necessary agreements been made with suppliers to ensure safe packaging and handling?
- Are there available markets for excess steam or electricity generated on site?
- Are there environmentally sound options available for the treatment and disposal of residues?

6.8.3 Additional factors in the siting of new sewage sludge incinerators

- Is there an accurate prediction of the nature and volume of sewage sludge generation in the area to be served?
- Will the supply allow for continuous operation of the incinerator?
- Has it been determined whether the sewage sludge in the service area is mixed with industrial or other wastes?
- Is it intended to co-incinerate the sewage sludge with municipal solid waste or as a supplemental fuel in a utility generating facility?
- Are there available markets for excess steam or electricity generated on site?
- Are there environmentally sound options available for the treatment and disposal of residues?

6.9 Modification of existing waste incinerators

Significant modifications to an existing waste incinerator may be considered for several reasons. These could include an expansion of capacity, the necessity of major repairs, enhancements to improve combustion efficiency and energy recovery, and the retrofitting of air pollution control and wastewater treatment devices. Many waste incineration plants have already been retrofitted with such devices, greatly improving their environmental performance. Before undertaking such a modification, in addition to the “priority consideration” noted above, the following factors will be important to consider:

- How will the modification affect the potential releases of chemicals listed in Annex C?
- If the modification is the addition of an air pollution control device, is it designed properly for the facility?
- Is there sufficient space to install and operate it according to best available techniques? For example, available space may dictate the retrofit of double filtration (filters in series, though not necessarily adjacent) rather than an alternative scrubbing system.
- Will the retrofitted device operate in concert with the existing air pollution and wastewater control devices to minimize releases?

The costs of making modifications to an existing facility depend on the plant-specific situation and may exceed similar changes at a new installation by 25–50% (European Commission 2006). Factors influencing this increase include the additional engineering necessary, the removal and disposal of replaced equipment, reconfiguring connections, and losses in productivity with down time.

7. Performance levels associated with best available techniques

With a suitable combination of primary and secondary measures, PCDD/PCDF performance levels in air emissions no higher than 0.1 ng I-TEQ/Nm^3 (at 11% O_2) are associated with best available techniques. It is further noted that under normal operating conditions emissions lower than this level can be achieved with a well designed waste incineration plant.

Best available techniques for discharges of waste water from effluent treatment plants, receiving flue gas treatment scrubber effluent, are associated with PCDD/PCDF concentration levels well below 0.1 ng I-TEQ/l.

References

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(ii) Medical waste

Summary

Incineration of medical waste (infectious health-care waste, biological health-care waste and sharps in dedicated waste incineration plants is performed in order to minimize chemical, biological and physical risks, and to reduce the volume of waste as a pretreatment step to environmentally sound landfilling.

If medical waste is incinerated in conditions that do not constitute best available techniques or best environmental practices, there is potential for the release of PCDD and PCDF in relatively high concentrations. For small medical waste incinerators, application of best available techniques is often difficult, given the high costs associated with building, operating, maintaining and monitoring such facilities.

Possible alternatives to incineration are sterilization (steam, advanced steam, dry heat), microwave treatment, alkaline hydrolysis, biological treatment or in certain cases landfilling. The most important step in managing medical waste is segregating different types of waste at the source. As between 75% and 90% of waste in hospitals is comparable to municipal solid waste, segregation greatly reduces the volume of medical waste. Effective waste management, including waste minimization and segregation at the source, is essential.

Appropriate treatment of bottom ashes and residues from flue gas cleaning is essential for the reduction of PCDD/PCDF releases into the environment. The use of best available techniques in incinerators will also reduce emissions of hydrochloric acid and metals (in particular mercury) and will also, in effect, reduce subsequent releases from residues disposed of into landfills.

With regard to incineration, primary measures alone will significantly reduce emission of the chemicals listed in Annex C of the Stockholm Convention. However, implementation of best available techniques requires both primary and secondary measures. .

With a suitable combination of primary and secondary measures, PCDD/PCDF emission levels in air emissions no higher than 0.1 ng I-TEQ/Nm^3 (at 11% O_2) are associated with best available techniques. It is further noted that under normal operating conditions emissions lower than this level can be achieved with a well designed waste incineration plant.

Best available techniques for discharges of waste water from effluent treatment plants, receiving flue gas treatment scrubber effluents, are associated with PCDD/PCDF concentration levels well below 0.1 ng I-TEQ/l.

1. Introduction

This section addresses best available techniques and best environmental practices in the (thermal) treatment of medical waste (referred to here as “health-care waste”), because the Stockholm Convention lists medical waste incinerators as a Part II source category that can result in significant emission of chemicals listed in Annex C of the Convention.

This section is concerned almost exclusively with infectious health-care waste. When wastes comparable to domestic waste are properly segregated from infectious wastes they can be dealt with by the municipal waste disposal mechanisms. However, in the absence of effective waste segregation practices and the management and training systems required to maintain them, the total quantity of potentially infectious waste requiring treatment rises dramatically.

Other possible techniques for treating health-care waste, for example the sterilization of infectious waste, do not result in emissions of chemicals listed in Annex C. The advantages, drawbacks and applicability of these techniques are already described elsewhere and are not repeated in detail here.

2. Health-care waste categories

Hospitals generate large amounts of waste that fall into different categories. Health-care waste can also originate from other sources, such as emergency medical care services, transfusion or dialysis centres, laboratories, animal research and blood banks. Between 75% and 90% of the waste produced is non-risk or general health-care waste, which is comparable to domestic waste. It comes mostly from the administrative and housekeeping functions of health-care establishments and may also include waste generated during maintenance of health-care premises. The remaining 10–25% of health-care waste is regarded as hazardous and may create a variety of health risks. Less than 10% of this waste is of an infectious nature. Other types of waste include toxic chemicals, cytotoxic drugs, and flammable and radioactive wastes.

Different types of health-care waste can be classified as follows:

- Infectious health-care waste (hazardous);
- Sharps (hazardous);
- Anatomical and pathological waste (body parts, etc.);
- Chemical, toxic or pharmaceutical waste, including cytotoxic drugs (antineoplastics) (mostly hazardous);
- Radioactive waste;
- General non-infectious waste (e.g. glass, paper, packaging material, food).

For the purpose of these guidelines, the following definitions are taken from *Technical Guidelines on the Environmentally Sound Management of Biomedical and Health-Care Waste* (Basel Convention Secretariat 2002).

2.1 Infectious health-care waste[3]

Infectious health-care waste includes discarded materials or equipment contaminated with blood and its derivatives, and other body fluids or excreta from infected patients with hazardous communicable diseases. It also includes contaminated waste from patients known to have blood-borne infections undergoing haemodialysis (e.g. dialysis equipment such as tubing and filters, disposable sheets, linen, aprons, gloves or laboratory coats contaminated with blood); and laboratory waste (cultures and stocks with any viable biological agents artificially cultivated to significantly elevated numbers, including dishes and devices used to transfer, inoculate and mix cultures of infectious agents and infected animals from laboratories).

2.2 Biological health-care waste

Biological health-care waste includes all body parts and other anatomical waste, including blood and biological fluids and pathological waste that is recognizable by the public or the health-care staff and that demand, for ethical reasons, special disposal requirements.

2.3 Sharps

Included in this category are all biomedical and health-care wastes with sharps or pointed parts able to cause an injury or invasion of the skin barrier of the human body. Sharps from infected patients with

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[3] The interpretation of the definition of infectious health-care waste varies according to national circumstances, policies and regulations. International organizations (WHO, the United Nations, etc.) have specific interpretations of the definition. Infectiousness is one of the hazardous characteristics listed in Annex III to the Basel Convention and defined under class H6.2.

hazardous communicable diseases or from isolated wards, or other pointed parts contaminated with the above-mentioned laboratory waste, must be categorized as infectious waste.

3. Alternative techniques for new and existing sources

3.1 New sources

When deciding on methods of waste treatment from health-care activities, priority consideration should be given to alternative processes, techniques or practices that have similar usefulness but which avoid the formation and release of chemicals listed in Annex C.

Due to the high investment, operational, maintenance and monitoring costs of waste incinerators using best available techniques, economical and effective plant operation is seldom achieved, especially for small hospital incinerators. This is also indicated by the fact that many small plants have been shut down instead of being retrofitted.

Therefore, in many cases on-site steam sterilization and other forms of non-combustion health-care waste treatment techniques may be preferred. In other cases, centralized waste treatment facilities are preferred to decentralized on-site treatment of health-care waste. The treatment of medical waste should then be an integral part of a country or region’s waste management plan.

3.2 Existing sources

Due to the poor design, operation, equipment and monitoring of many existing small hospital incinerators these installations cannot be regarded as employing best available techniques. A medical waste incinerator without sophisticated pollution abatement devices releases a wide variety of pollutants, including PCDD/PCDF, metals (such as lead, mercury and cadmium), particulate matter, acid gases (hydrogen chloride (HCl) and sulphur dioxide (SO_2)), carbon monoxide (CO) and nitrogen oxides (NO_x). These emissions have serious adverse consequences on worker safety, public health and the environment.

The cost of retrofitting old plants is a key factor in the consideration of medical waste disposal. In evaluating the costs of an incineration unit employing best available techniques, decision makers should take into account several factors, including: capital and operating costs of the incinerator plus scrubber and other pollution control devices; the cost of secondary chamber retrofits for old incinerators; the costs of periodic stack testing, continuous monitoring, operator training and qualification; and the costs of maintenance and repair, especially in relation to refractory wear or failure.

As a consequence, the shutdown of existing inappropriate plants has to be considered along with the introduction of alternative techniques for waste treatment or the transfer of waste to centralized health care waste treatment facilities.

3.3 Alternative techniques

The following alternative techniques do not result in the formation and release of chemicals listed in Annex C and should therefore be given priority consideration for their ultimate elimination. However, they might have advantages and drawbacks in other respects. For more information on these techniques see Basel Convention Secretariat 2002.

The following methods are suitable for infectious and biological waste and sharps and are widely applied.[4] The establishment of an effective waste management programme, as described in subsection 4 of the present section, is essential for all the techniques described below. Hazardous chemical waste, chemotherapeutic waste, volatile organic compounds, mercury and radioactive waste should not be

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[4] Cost data on the various techniques can be obtained from *Non-Incineration Medical Waste Treatment Technologies*, chapter 11 (Health Care Without Harm 2001).

fed into the systems described here, as this would result in the release of toxic substances into air, condensate or into the treated waste.

Alternative techniques such as sterilization techniques, microwave treatment, alkaline hydrolysis and biological treatment still require final disposal in sanitary landfills.

Workers should be provided with training in such skills as the proper handling of waste and equipment operation and maintenance. Another issue relates to occupational exposure to the chemical disinfectant itself through fugitive emissions, accidental leaks or spills from storage containers, discharges from the treatment unit or volatilized chemicals from treated waste or liquid effluent. Chemical disinfectants are sometimes stored in concentrated form, thus increasing the hazards.

Since chemical processes usually require shredding, the release of pathogens through aerosol formation may be a concern. Chemical-based technologies commonly operate as closed systems or under negative pressure passing their air exhaust through HEPA (high efficiency particulate absorbing) and other filters.

Health care facilities should consider the following factors when selecting a non-incineration technology (Health Care Without Harm Europe 2004):

- Regulatory acceptance;
- Throughput capacity;
- Types of waste treated;
- Microbial inactivation efficacy;
- Environmental emissions and waste residues;
- Space requirements;
- Utility and other installation requirements;
- Waste reduction;
- Occupational safety and health;
- Noise;
- Odour;
- Automation;
- Reliability;
- Level of commercialization;
- Background of the technology manufacturer or vendor;
- Cost;
- Community and staff acceptance.

3.3.1 Steam sterilization

Steam sterilizing or autoclaving is the exposure of waste to saturated steam under pressure in a pressure vessel or autoclave. The technology does not render waste unrecognizable and does not reduce the waste volume unless a shredder or grinder is added. If waste streams are not properly segregated to prevent hazardous chemicals (e.g. antineoplastic drugs or heavy metals such as mercury) from being fed into the treatment chamber, toxic contaminants will be released into the air, condensate, or in the treated waste. Offensive odours containing low levels of alcohol, phenols, aldehydes, and other organic compounds can be generated but can be minimized by proper air handling equipment (e.g. by particulate and carbon filters). More independent emission tests of autoclaves operating under typical conditions would be useful.

Autoclaves are available in a wide range of sizes, from units that treat a few kilograms per cycle to several tons per cycle. Capital costs are relatively low compared to other alternative techniques. Autoclaves have to be inspected at least annually to determine if there are any significant changes from the previous temperature-time profiles, vacuum and steam pressure readings.

The treatment cycle (minimum requirement is 121°C for 30 minutes) is determined by the ability of the heat to penetrate the waste load. Some types of waste or loading configurations that create barriers to heat transfer require longer exposure times and/or higher temperatures. The proper level of disinfection has to be controlled by appropriate means (e.g. test strips, microbiological tests).

3.3.2 Advanced steam sterilization systems

Advanced autoclaves or advanced steam sterilization systems combine steam treatment with prevacuuming and various kinds of mechanical processing before, during and after steam treatment. Many of the advanced systems also include automated waste feed systems; post-treatment vacuum/dehydration; cooling of treated waste; and high-efficiency particulate air filtration and/or carbon filters to remove odours.

Advanced systems with internal shredders or grinders are capable of treating sharps waste as well as pathological waste, including anatomical parts. Drawbacks include the relatively higher capital costs, and the noise generation and higher maintenance costs associated with the shredders and other mechanical devices.

As with steam sterilization, advanced steam sterilization requires proper waste segregation to avoid releases of hazardous substances into different media (see Figure 1 below).

3.3.3 Microwave treatment

Microwave disinfection is essentially also a steam-based process since disinfection occurs through the action of moist heat and steam generated by microwave energy. Microwave units with internal shredders can treat pathological waste and are routinely used to treat sharps waste. Drawbacks are the relatively high capital costs, noise generation from the shredder and the possibility of offensive odours. Offensive odours containing low levels of alcohol, phenols, aldehydes, and other organic compounds can be generated but can be minimized by proper air handling equipment (e.g. by particulate and carbon filters).

3.3.4 Dry heat sterilization

Dry heat sterilization is the exposure of the waste to heat at a temperature and for a time sufficient to ensure sterilization of the entire waste load. As a general rule, dry heat processes use higher temperatures and longer exposure times than steam-based processes. Internal shredding is usually included (for reduction of waste volume). The technology is simple, automated and easy to use.

Volatile and semi-volatile organic compounds, chemotherapeutic wastes, mercury, other hazardous chemical wastes, and radiological wastes should not be treated in a dry heat system. Offensive odours can occur, which are removed in some systems with high-efficiency particulate air or carbon filters. The hot air from the chamber is cooled in a venturi scrubber, which also removes particulates.

3.3.5 Alkaline hydrolysis

Alkaline hydrolysis (or heated alkali digestion) is another chemical process used for the breakdown of organic materials. The same process can degrade bulk chemotherapeutic agents, formaldehyde, fixatives and other toxic chemicals. A typical process uses a sealed stainless steel tank, where waste is mixed with alkali heated to around 110 °C to 150 °C. Depending on the amount of waste, alkali concentration and temperature, the process of digestion can take 3 to 8 hours. Commercial systems are highly automated. Treatment of waste and liquids from alkaline hydrolysis may be necessary.

3.3.6 Biological treatment

Biological treatment involves the use of micro-organisms or biochemicals to decompose the waste. These include the use of enzymes and aerobic or anaerobic digestion. Preferably treatment should take place in a closed system. Offensive odours may result from the application of anaerobic treatment.

3.3.7 Specially engineered landfill

(a) Infectious wastes (i.e. Infectious health-care waste, sharps anatomical and pathological wastes):

Such wastes should not be disposed of to landfill. However, if sterilized they may be regarded as general noninfectious waste and either landfilled or treated in accordance with Section V.A.(i) above (except for sharps, which must also be considered in the light of their physical characteristics).

(b) Chemical, toxic and pharmaceutical wastes and general wastes:

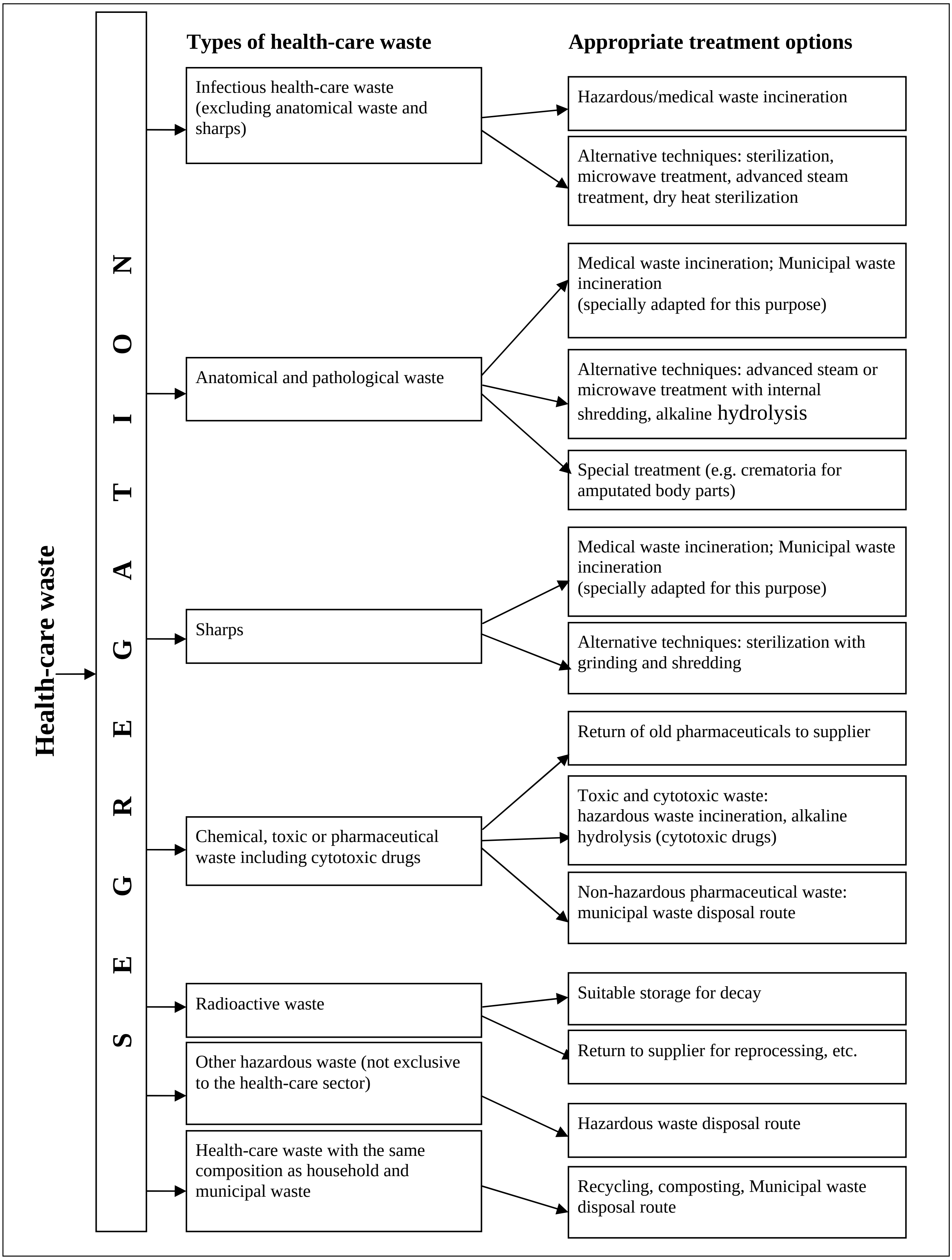
A specially engineered landfill may be an option for such wastes but careful attention must be given to their individual physical and chemical characteristics.

(c) Radioactive wastes:

This waste should not be landfilled.

Figure 1 (Basel Convention Secretariat 2002, chapter 2, Figure 2, adapted) shows into which waste fractions the health-care waste should be segregated and suggests treatment options for these fractions.

Figure 1. Segregation and treatment options for health-care waste



4. Best environmental practices for health-care waste management

Each hospital should develop a waste management plan that provides for thorough segregation and treatment of waste. This can lower the costs of the ultimate disposal. A waste management plan of one hospital can also include treatment of certain fractions of waste from other hospitals to lower costs and to increase the environmental performance of overall waste management.

The main aims of hospital waste management are:

- Minimizing risk for personnel, the general public and the environment;
- Minimizing the amounts of waste being generated;
- Providing for segregation and separation of wastes;
- Designation of deposit areas in the wards;
- Establishment of safe routes for the transportation of the waste;
- Establishment of a safe and proper area for temporary storage;
- Environmentally sound waste treatment and disposal.

Under the framework of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, *Technical Guidelines on the Environmentally Sound Management of Biomedical and Health-Care Waste* has been published (Basel Convention Secretariat 2002). Use and application of these guidelines, which provide detailed information on the hazards of health-care waste, safe management of health-care waste, the proper segregation and collection of wastes, treatment and disposal methods, and capacity-building, is strongly advised.

In the establishment of a proper health-care waste management plan it is necessary to:

- Characterize the nature and amount of the different waste fractions;
- Identify options to avoid or reduce waste generation (purchasing policies that avoid unnecessary packaging, optimized package sizes, stock keeping, evaluation of work processes, reuse of supplies and equipment where safe and feasible);
- Establish training and management systems to assure effective segregation and handling of infectious, toxic and ordinary wastes;
- Specify suitable containers for collection, storage and transport;
- Lay down the responsibilities of the personnel;
- Describe the appropriate treatment options for the different waste fractions;
- Provide for proper documentation and control of waste disposal;
- Describe the transport of the waste fraction to the final disposal location and the type of final treatment;
- Calculate the costs for the different activities.

Prior to efficient and state-of-the-art treatment and disposal a number of practices are considered necessary. The practices described below can be directly linked to the reduction and avoidance of chemicals listed in Annex C but represent general principles that can influence the generation of waste fractions and contribute to the safety of personnel, the public and the environment.

For more detailed information ample material concerning health-care waste management is available from different sources (Basel Convention Secretariat 2002; WHO 2000; Health Care Without Harm Europe 2004).In this document only a brief overview of common best practices is given.

4.1 Source reduction

Source reduction means minimizing or eliminating the generation of waste at the source itself. Source reduction should have a higher priority than recycling or reuse. Medical staff, waste managers and product standardization committees should be aware of what proportions of the waste stream are generated by the products they buy. Indeed, the close involvement of purchasing staff is critical to the effectiveness of any source reduction scheme. Steps should be taken to reduce at source regulated medical waste, hazardous waste, low-level radioactive waste, as well as regular trash. Some specific source reduction techniques include (bearing in mind that alternative products have to meet the relevant requirements in terms of hygiene and patient safety):

- Material elimination, change or product substitution;
- Technology or process change;
- Preferential purchasing;
- Good operating practice.

4.2 Segregation

Above all, segregation is the key to effective health-care waste management. It ensures that correct disposal routes are taken. Wastes should be separated according to the treatment options suggested. Segregation should be carried out under the supervision of the waste producer and as close as possible to the source, that is, in the ward, at the bedside, in the theatre, in the laboratory, in the delivery room, etc., and must be carried out by the person generating the waste, for example the nurse, the doctor or the specialist, in order to secure the waste immediately and to avoid dangerous secondary sorting.

4.3 Resource recovery and recycling

Specific examples of means recovery and reuse of materials from the waste stream include:

- Recycling newspapers, packaging material, office paper, glass, aluminium cans, construction debris, and other recyclables;
- Purchasing products made of post-consumer recycled material;
- Composting organic food waste;
- Recovering silver from photographic chemicals.

4.4 Training of personnel

Personnel should receive thorough instructions about:

- Risks connected with health-care waste;
- Classification and codes of the different waste fractions and their classification criteria;
- Costs of waste treatment;
- Waste management processes from generation to disposal;
- Operation and maintenance of waste treatment facilities;
- Responsibilities;
- Effects of mistakes and mismanagement.

4.5 Collection at the site of waste generation

- Provide colour-coded containers at or near the points of generation for segregation of the different waste types

- Proper packaging of the waste: either solid containers or plastic bags placed within a rigid or semi-rigid container should be used for non-sharps infectious waste. The plastic bags should be impervious to moisture, and have strength sufficient to resist tearing or bursting when used under normal conditions. Containers for sharps waste should be rigid, puncture resistant and leak proof. The containers may be recyclable (metal or autoclavable plastic) or single use (thick cardboard or plastic). Sharps containers should have a closing lid;
- Proper labelling of waste containers e.g. as infectious or cytotoxic;
- Containers should not be more than three quarters full;
- Highly infectious waste should, whenever possible, be sterilized immediately by autoclaving. It therefore needs to be packaged in bags that are compatible with the proposed treatment process.

4.6 Transport to the intermediate storage area

- Once the primary containers are full they must be taken to an intermediate storage area;
- Establish a designated storage area following the WHO recommendations where access is only allowed for authorized personnel;
- Personnel handling the waste must wear protective clothing (gloves, shoes) during collection, transportation and storage;
- Clear transport routes and times;
- No compaction of containers containing sharps or other infectious waste should take place;
- No manual sorting of infectious waste fractions.

5. Applied techniques for the incineration of health-care waste

5.1 Process description

Open burning of health-care wastes should not be carried out. Incineration is an important method for the treatment and decontamination of biomedical and health-care waste. This subsection gives guidance on the incineration of the following (mostly) hazardous waste fractions: infectious health-care waste, biological health-care waste and sharps.

Incineration is a high-temperature (850 °C to 1,100 °C) dry oxidation process that reduces organic and combustible waste to inorganic, incombustible matter and results in a very significant reduction of waste volume and weight.

Pyrolysis is a process of smouldering whereby thermal conversion occurs in an oxygen-deficient atmosphere at a temperature between 500 °C and 600 °C.

Incineration or pyrolysis should only be carried out in well-designed operated and maintained plants. The system should be designed to cope with the specific characteristics of hazardous health-care waste (high water content, high plastic content). As the following technologies are rather sophisticated only hazardous waste fractions should be burnt in these plants. Other health-care waste that is similar to municipal waste should be segregated in advance and be subject to different waste treatment technologies.

If infectious waste is not burnt immediately (during 48 hours) it must be deposited in a cooled storage room (10 °C maximum). Working and storage areas should be designed to facilitate disinfection.

An incineration plant basically consists of the following units (Figure 2):

- Furnace or kiln;
- Afterburning chamber;
- Dry, wet and/or catalytic flue gas cleaning devices (including adsorption techniques);

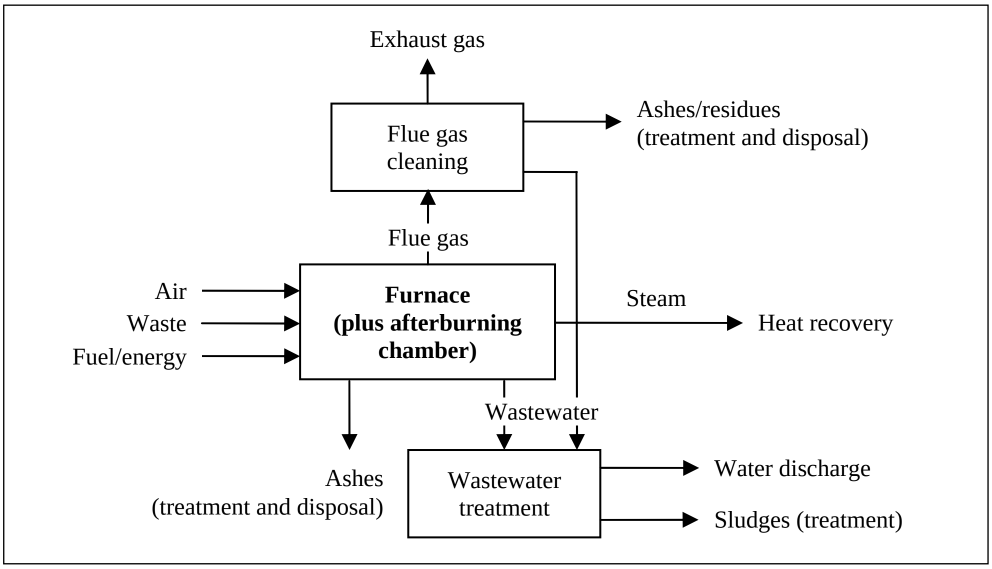
- Wastewater treatment plant (in case wet systems are used for flue gas treatment).

The following technologies are considered best available techniques for the thermal treatment of health-care waste:

- Pyrolytic treatment or gasification of wastes;
- Rotary kiln;
- Grate incinerator specially adapted for infectious health-care waste (municipal waste disposal line);
- Fluidized bed incinerator;
- Modular systems.

Single-chamber, drum and brick incinerators are not considered best available techniques.

Figure 2. Simplified flow scheme of an incinerator



5.2 Thermal treatment techniques

5.2.1 Pyrolysis plants

Pyrolysis plants with afterburning chambers are usually small plants operating in a discontinuous mode. Health-care waste is packed in barrels or bags for charging. Larger plants should be equipped with automatic loading devices. At plants with degassing or gasification systems, drying, degassing and gasification take place in a reactor prior to combustion.

Waste is introduced discontinuously into a distillation chamber, which is heated up to a sufficient temperature to distil the waste. Gases leaving the distillation chamber are mixed with a continuous airflow in the afterburning chamber and held at a temperature of about 900 °C by co-firing of supplementary fuel. Combustion gases leaving the afterburning chamber are cooled in a downstream hot water boiler and routed to a flue gas cleaning system. The boiler converts water into steam. The steam can be used to produce electricity to run a hospital, homes or businesses. In order to ensure sufficient burnout of the ash it is fired with gas burners before it is discharged from the distillation chamber. At small plants fluctuations in throughput and variations in combusted waste content are compensated by the auxiliary fuels.

In pyrolysis plants the dust content of flue gases is small compared to conventional combustion systems. However, there is great demand for additional fuels, so that consequently high volumes of flue gas are formed.

Typical capacities (on-site treatment): 200 kg to 10 tons per day.

5.2.2 Rotary kiln

Another technology used is the rotary kiln (see also section V.A (i), subsection 2.2 of the present guidelines). The combustion of health-care waste can be performed in either small rotary kilns (for example, in the hospital) or, more commonly, in larger plants used for the combustion of several hazardous waste fractions.

Wastes are delivered by crane from the bunker into the waste chute, which is located in front of the firing chamber. In most cases a sluice is integrated into the chute where waste can directly be fed into the rotary kiln. Highly viscous and liquid wastes can be inserted through the front wall of the rotary kiln. As a result of the slope and the rotation of the rotary kiln, wastes are transported and circulated, which leads to intensive contact with primary air that flows through the rotary kiln. In contrast to grate firings rotary kilns are closed systems. Therefore liquid and highly viscous materials can also be inserted. Exhaust gases coming out of the rotary kiln are treated in an afterburning chamber. In order to ensure the high temperatures necessary for complete destruction of organic compounds (850°–1,100 °C, depending on the waste) afterburning chambers are equipped with burners that automatically start when the temperature falls below the given value.

At the end of the rotary kiln slag, either sintered or melted, arises. By dropping this into the water of the deslagging unit, granulated slag is formed. When the slag is sintered, this part of the plant is similar to that of a grate firing system. Rotary kilns and afterburning chambers are in most cases constructed as adiabatic, ceramic-lined combustion chambers. After the combustion chamber flue gases pass a void zone until a temperature of about 700 °C is reached. Subsequently heating bundles such as evaporators, superheaters and feed water preheaters are arranged. The waste heat boiler and energy supply system is comparable to that of grate firing systems.

Incinerator capacities: 0.5 to 3 tons per hour (for health-care waste incineration).

5.2.3 Grate incinerator

Incineration of health-care waste in municipal waste incinerators requires special adaptations. If infectious health-care waste is to be burnt in a municipal waste incinerator it has to be disinfected and sterilized beforehand or fed into the incinerator in appropriate containers by automatic loading. Previous mixing of infectious waste with other waste types and direct handling has to be avoided. See section V.A (i) of the present guidelines for further information about municipal waste incineration.

5.2.4 Fluidized bed incinerator

Fluidized bed incinerators are widely applied to the incineration of finely divided wastes such as refuse-derived fuel and sewage sludge. The method has been used for decades, mainly for the combustion of homogeneous fuels. The fluidized bed incinerator is a lined combustion chamber in the form of a vertical cylinder. In the lower section, a bed of inert material (e.g. sand or ash) on a grate or distribution plate is fluidized with air. The waste for incineration is continuously fed into the fluidized sand bed from the top or side.

Preheated air is introduced into the combustion chamber via openings in the bed plate, forming a fluidized bed with the sand contained in the combustion chamber. The waste is fed to the reactor via a pump, a star feeder or a screw-tube conveyor. In the fluidized bed drying, volatilization, ignition and combustion take place. The temperature in the free space above the bed (the freeboard) is generally between 850 °C and 950 °C. Above the fluidized bed material, the freeboard is designed to allow retention of the gases in a combustion zone. In the bed itself the temperature is lower, and may be around 650 °C. Because of the well-mixed nature of the reactor, fluidized bed incineration systems generally have a uniform distribution of temperatures and oxygen, which results in stable operation.

For heterogeneous wastes, fluidized bed combustion requires a preparatory process step for the waste so that it conforms to size specifications. For some waste this may be achieved by a combination of selective collection of wastes or pretreatment, such as shredding. Some types of fluidized beds (for example, the rotating fluidized bed) can receive larger particle size wastes than others. Where this is the case the waste may only require a rough size reduction, or none at all.

5.2.5 Modular systems

Modular systems are a general type of (municipal solid) waste incinerator used widely in the United States of America, Europe and Asia. Modular incinerators consist of two vertically mounted combustion chambers (a primary and secondary chamber). In modular configurations combustion capacity typically ranges from 1 to 270 tons per day. There are two major types of modular systems, excess air and starved air:

- The modular excess air system consists of a primary and a secondary combustion chamber, both of which operate with air levels in excess of stoichiometric requirements (i.e., 100–250% excess air);
- In the starved (or controlled) air type of modular system, air is supplied to the primary chamber at substoichiometric levels. The products of incomplete combustion entrain in the combustion gases that are formed in the primary combustion chamber and then pass into a secondary combustion chamber. Excess air is added to the secondary chamber, and combustion is completed by elevated temperatures sustained with auxiliary fuel (usually natural gas). The high, uniform temperature of the secondary chamber, combined with the turbulent mixing of the combustion gases, favours low levels of particulate matter and organic contaminants being formed and emitted.

5.3 Flue gas cleaning

Flue gases from incinerators contain fly ash (particulates) contaminated with metals, PCDD/PCDF, thermally resistant organic compounds, and gases such as nitrogen oxides, sulphur oxides, carbon oxides and hydrogen halides. Flue gases resulting from uncontrolled batch mode (no flue gas cleaning) will contain around 2,000 ng I-TEQ/m³ (UNEP 2005).[5]

Appropriate flue gas cleaning measures have to be combined in a suitable manner to ensure the application of best available techniques (see section III.C (iv) and also V.A. (i) 6.4 of the present guidelines).

5.4 Fly and bottom ash treatment, wastewater treatment

The main waste fractions are fly ash, slag, filter cake from the wastewater treatment, gypsum and spent activated carbon. These wastes are predominantly hazardous wastes and have to be disposed of in safe landfills. Landfilling in proper double-walled containers, solidification and subsequent landfilling, and thermal post-treatment are the most common methods (see also section V.A (i), subsection 5 of the present guidelines).

6. Best available techniques and summary of best environmental practices

In addition to applying best environmental practices to the incineration of medical waste there is a variety of demonstrated combustion engineering, flue gas cleaning and residue management techniques that are available for preventing the formation or minimizing the releases of chemicals listed in Annex C. For a detailed analysis of what represents best available techniques for waste incineration reference should be made to the European Commission BAT Reference (BREF) Document on waste incineration (European Commission 2006).

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[5] 1 ng (nanogram) = 1 × 10^{-12} kilogram (1 × 10^{-9} gram); Nm^3 = normal cubic metre, dry gas volume measured at 0°C and 101.3 kPa. For information on toxicity measurement see section I.C, subsection 3 of the present guidelines.

There are also non-incineration technology options (see section III.C (ii) of the present guidelines) that may represent feasible and environmentally sound alternatives to incineration. The purpose of this subsection, however, is to identify the best techniques applicable to the process of incineration. Best available techniques for incineration include the design, operation and maintenance of a waste incineration plant that effectively minimizes the formation and release of chemicals listed in Annex C.

When considering the best available techniques described here for waste incineration, it is important to consider that the optimal solution for a particular type of incineration installation varies according to local conditions. The best available techniques provided here are not intended as a checklist indicating the best local solution, as this would require the consideration of local conditions to a degree that cannot be described in a document dealing with best available techniques in general. Hence, the simple combination of the individual elements described here as best available techniques, without consideration of local conditions, is not likely to give the optimized local solution in relation to the environment as a whole (European Commission 2006).

The use of best available techniques in incinerators will also reduce emissions of hydrochloric acid and metals (in particular mercury). Appropriate treatment of bottom ashes and residues from flue gas cleaning is essential for the reduction of PCDD/PCDF releases into the environment and will reduce subsequent releases from residues disposed of into landfills.

With regard to incineration, primary measures alone will significantly reduce emission of the chemicals listed in Annex C of the Stockholm Convention. However, implementation of best available techniques requires both primary and secondary measures. With a suitable combination of primary and secondary measures, PCDD/PCDF performance levels in air emissions no higher than 0.1 ng I-TEQ/Nm^3 (at 11% O_2) are associated with best available techniques. It is further noted that under normal operating conditions emissions lower than this level can be achieved with a well designed waste incineration plant.

Best available techniques for discharges of waste water from effluent treatment plants, receiving flue gas treatment scrubber effluents, are associated with PCDD/PCDF concentration levels well below 0.1 ng I-TEQ.

A summary of what constitutes best environmental practice and best available techniques for medical waste incineration is presented in the tables below.

Table 1. General guidance

Measure	Description	Considerations	Other comments
Segregation of waste	Clear classification, segregation at source of health-care waste from other waste and within the health-care waste category to minimize the amount of waste to be treated		Can be directly effective for reduction of chemicals listed in Annex C but part of an integrated concept for the management of waste
Alternative processes	In particular, if performance requirements cannot be met by the existing or planned facility, priority consideration should be given to alternative processes with potentially less environmental impacts than waste incineration	Alternative processes to incineration of infectious health-care waste include: • Steam sterilization • Advanced steam sterilization • Microwave treatment • Dry heat sterilization • Biological treatment • Alkaline hydrolysis • Landfill	

Table 2. Health-care waste incineration: Firing technologies representing best available techniques

Technology	Considerations	Other comments
Pyrolysis plants	Suitable for smaller plants (200 kg/day to 10 tons/day) and on-site treatment	High investment and maintenance costs, well-trained personnel required
Rotary kiln	Suitable for medium-sized plants (0.5–3 tons/hour)	Use of water cooling for rotary kilns, high investment and maintenance costs, well-trained personnel required, high energy consumption
Incinerator with grate (municipal waste incinerator)		Use of water cooling for grates, incineration in municipal waste incinerators requires special adaptations for health-care waste (e.g. automatic loading), no previous mixing or direct handling of infectious health-care waste
Fluidized bed incinerator		
Modular systems	Ranges from 1 to 270 tons per day	

Table 3. Health-care waste incineration: General measures

Management options	Release characteristics	Other considerations
No burning of waste unless specific measures for reduction of chemicals listed in Annex C are taken (both primary and secondary measures, as appropriate; see Tables 5 and 6))	Possible releases of Annex C compounds and volatile metals	Be aware of possible halogen content in the waste and take the appropriate primary and secondary measures (see Table 5 and 6). Be aware of possible heavy metal content in the waste and take appropriate secondary measures (see Table 6).
Appropriate transport, storage and security of health-care waste according to the needs of types of waste	Not directly effective for reduction of chemicals listed in Annex C but part of an integrated concept for the management of waste	
Location of the plant: Centralized incineration units are preferred to decentralized on-site treatment of hazardous health-care waste		
Incineration of health-care waste only in dedicated plants or in larger incinerators for hazardous waste		The characteristics of health-care waste (high water and plastics content) require special equipment
If a dedicated health-care waste incinerator is not used a separate charging system for infectious waste should be applied	Not directly effective for reduction of chemicals listed in Annex C but part of an integrated concept for the management of waste	
Do not burn radioactive waste	Not effective for reduction of chemicals listed in Annex C	

Table 4. Health-care waste incineration: Organizational measures

Measure	Considerations
• Well-trained personnel • Operation and monitoring of the incinerator by periodic maintenance (cleaning of combustion chamber, declogging of air inflows and fuel burners, personnel should wear protective clothing) • Regular and/or continuous measurement of the relevant pollutants • Development of environmental monitoring (establishing standard monitoring protocols) • Development and implementation of audit and reporting systems • General infrastructure, paving, ventilation • Environmental impact assessment, public hearings and community input prior to siting of new incinerators	Operation of incinerators requires qualified incinerator operators. It should be remembered that qualified operators should be available for the whole operating period of the incinerator (i.e. 20 and more years as a rule). The availability of such operators in certain regions should be verified before purchasing high-technology incinerators. If qualified operators are not available, health-care establishments should either resort to alternative health-care waste disinfection technologies or contract the incineration out through a regional facility. In a similar way long-term contracts should be signed about issues such as maintenance and repair, retrofitting (if necessary) and final treatment and disposal of solid residues generated by incineration.

Table 5. Primary measures and process optimization to reduce PCDD/PCDF emissions

Management options for optimization of combustion conditions	Other considerations
Introduction of the waste into the combustion chamber only at temperatures of 850 °C; plants should have and operate an automatic system to prevent waste feed before the appropriate temperature is reached	Retrofitting of the whole process needed
Installation of auxiliary burners (for start-up and close-down operations)	
In general, avoidance of starts and stops of the incineration process	
Avoidance of temperatures below 850 °C and cold regions in flue gas	
Sufficient oxygen content; control of oxygen input depending on the heating value and consistency of feed material	At oxygen content: 6% vol.
Sufficient residence time (minimum 2 sec.) in a secondary combustion chamber after the last injection of air and temperature above 850 °C (1,100 °C for highly chlorinated wastes, i.e. wastes with more than 1% halogenated organic substances) and 6% O_2	Sufficient residence time is required especially because of the plastic and water content of the waste
High turbulence of exhaust gases and reduction of air excess: e.g. injection of secondary air or recirculated flue gas, preheating of the air streams, regulated air inflow	Optimized air inflow contributes to higher temperatures
(Online) monitoring for combustion control (temperature, oxygen content, CO, dust), operation and regulation of the incineration from a central console	

Table 6. Secondary measures

Management options	Release characteristics	Applicability	Other considerations
Dedusting			
Avoiding particle deposition by soot cleaners, mechanical rappers, sonic or steam soot blowers, frequent cleaning of sections that are passed by flue gas at the critical temperature range			Steam soot blowing can increase PCDD/PCDF formation rates
Effective dust removal by the following measures:	< 10 % remaining emission in comparison to uncontrolled mode	Medium	Removal of PCDD/PCDF adsorbed onto particles
Fabric filters	1–0.1% remaining emission	Higher	Use at temperatures < 260 °C (depending on material)
Ceramic filters			Emerging technique. Use at temperatures 800 °C – 1,000 °C, not common for waste incinerators
Cyclones (only for precleaning of flue gases)	Low efficiency	Medium	Only efficient for larger particles
Electrostatic precipitation	Medium efficiency		Use at a temperature of 450 °C; promotion of de novo synthesis of PCDD/PCDF possible, low efficiency for fine particles, higher NO_x emissions, reduction of heat recovery
High-performance adsorption unit with added activated charcoal particles (electrodynamic venturi)			For fine dust removal
Reduction of emissions of chemicals listed in Annex C by:			
Catalytic oxidation	High efficiency (< 0.1 ng TEQ/m^3)	High investment, low operating costs	Only for gaseous compounds, previous removal of heavy metals and dust necessary, additional NO_x reduction if NH_3 is added; high space demand, catalysts can be reprocessed by manufacturers in most cases, overheating when too much CO present, higher energy consumption due to reheating of flue gas; no solid residues
Gas quenching			Not common in waste incinerators
Fabric filter coated with catalyst	High efficiency (< 0.1 ng TEQ/m^3)		e.g. made from PTFE, with parallel dedusting, lower contamination of filter dusts because of PCDD/PCDF destruction at the catalytic surface
Different types of wet and dry adsorption methods with mixtures of activated charcoal, open hearth coke, lime and limestone solutions in fixed bed, moving bed and fluidized bed			

Management options	Release characteristics	Applicability	Other considerations
reactors:			
Fixed bed reactor, adsorption with activated charcoal or open hearth coke	< 0.1 ng TEQ/m^3	High investment, medium operating costs	High demand of space, disposal of solid residues from flue gas cleaning (= hazardous waste) necessary, permanent monitoring of CO necessary, increase of dust emissions due to aggregation with coal particles possible, consumption of open hearth coke in comparison with activated charcoal 2 to 5 times higher, incineration of used adsorption agent in the plant possible, fire/explosion risk
Entrained flow or circulating fluidized bed reactor with added activated coke/lime or limestone and subsequent fabric filter	< 0.1 ng TEQ/m^3	Low investment, medium operating costs	Not common for plants burning exclusively health-care waste, disposal of solid residues from flue gas cleaning (= hazardous waste) necessary, fire/explosion risk
Appropriate fly and bottom ash and wastewater treatment: • Disposal in safe landfills (e.g. underground disposal) • Catalytic treatment of fabric filter dusts under conditions of low temperatures and lack of oxygen • Scrubbing of fabric filter dusts by the 3-R process (extraction of heavy metals by acids) • Combustion for destruction of organic matter (e.g. rotary kiln, Hagenmeier-Trommel) with subsequent fabric filter, scrubber • Vitrification of fabric filter dusts or other immobilization methods (e.g. solidification with cement) and subsequent landfilling • Application of plasma technology (emerging technique)			Sludges from wastewater treatment and from cooling of fly ash are hazardous waste. Flue gas can be lead back into the combustion chamber of the incinerator

7. Performance levels associated with best available techniques

With a suitable combination of primary and secondary measures, PCDD/PCDF performance levels in air emissions no higher than 0.1 ng I-TEQ/Nm^3 (at 11% O_2) are associated with best available techniques. It is further noted that under normal operating conditions emissions lower than this level can be achieved with a well designed waste incineration plant.

Best available techniques for discharges of waste water from effluent treatment plants, receiving flue gas treatment scrubber effluents, are associated with PCDD/PCDF concentration levels well below 0.1 ng I-TEQ/l.

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