

**GUIDELINES ON BEST AVAILABLE
TECHNIQUES AND PROVISIONAL GUIDANCE
ON BEST ENVIRONMENTAL PRACTICES**

**relevant to Article 5 and Annex C
of the Stockholm Convention on
Persistent Organic Pollutants**

Crematoria



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■ Summary

From early history to the present day cremation has been a religiously and culturally important and accepted practice used by many cultures and countries as a way of dealing with the death of human beings. In many cases, cremation is integral to the religious and funeral practices of a particular country or culture; in others, it is a voluntary alternative to burial. These guidelines are not an attempt to redefine these practices or to demean their significance for the people involved. For those countries where cremation is practised and in keeping with the provisions of the Stockholm Convention, these guidelines seek to provide approaches that minimize or eliminate the formation and release of chemicals listed in Annex C of the Convention during the process of cremation.

The formation and release of PCDD and PCDF, HCB and PCB from crematoria is possible due to the presence of these chlorinated materials, precursors and chlorine in the cadavers and in some co-combusted plastics. Measures to minimize formation and release of chemicals listed in Annex C would include the avoidance of chlorinated material, the design of crematoria to deliver a minimum furnace temperature of 850°C, a 2-second residence time for the combustion gases and sufficient air to ensure combustion. Larger new crematoria should also be fitted with air pollution control equipment to minimize emission of sulphur dioxide, hydrogen chloride, carbon monoxide, volatile organic compounds, particulate matter and persistent organic pollutants. Performance levels of < 0.1 ng I-TEQ/Nm³ for PCDD/PCDF in air emissions are associated with best available techniques.

1. Process description

Cremation is the disposal of a cadaver by the process of burning. This can be undertaken in either an uncontrolled, open burning fashion on funeral pyres, or in a controlled fashion within a cremator, installed within a crematorium or crematory. For the purposes of this document, only the cremator installations are discussed with respect to preventing releases of persistent organic pollutants, and not open burning or non-combustion alternatives. It is noted, however, that in certain countries, cultural and societal practices can dictate the types of processes that are available for cadaver disposal. Proper consideration of such issues is therefore important.

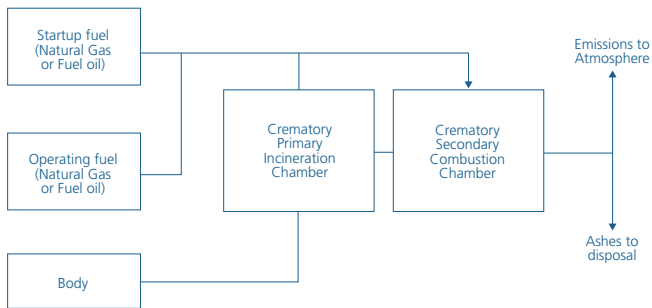
Cremators typically consist of two main combustion chambers (Figure 1). The first, or primary, contains the hearth on which the coffin is received. This is supplied with forced draught air and one or two main support burners (typically in the order of 200–300 kW). These are usually gas fired, although in some locations they are oil fired. There are also a few designs of electrically heated cremators in operation. Primary chambers are typically between 1.5 and 2.5 m³. Burning of the coffin and cadaver takes place on the fixed hearth and combustion gases, products of incomplete combustion and entrained

particulate material produced by this process are then passed into the secondary combustion chamber.

Within the secondary chamber, further combustion air may be added, and an afterburner system supports completion of combustion. The secondary chamber is sometimes also used to preheat combustion air for the primary chamber.

Combustion gases are ejected from the cremator by either an induced draught fan or venture ejector system. Few countries require air pollution control equipment to be installed following the cremator, but where it is installed, the system typically adopted is the dry injection/filtration system. Here a suitable adsorbent, such as a mix of powdered lime and activated carbon, is injected into the cooled gas stream, and then a high-efficiency bag filter arrangement removes the injected powder together with entrained particulate matter. In the United Kingdom, for example, new crematoria and some existing crematoria are to be fitted with such adsorption systems for control of mercury emissions, which will have the co-benefit of controlling dioxin emissions.

■ **Figure 1. Schematic of a typical cremation process**



Many installations worldwide are equipped with cremators of an older design incorporating smaller secondary chambers, with short gas residence times and occasionally with no afterburner arrangement installed. Older cremators often rely on manual control, with an operator deciding burner duration and air distribution.

Cremation is a religiously and culturally important and accepted practice for many cultures and countries as a way of dealing with the death of human beings. In many cases, cremation is integral to the religious and funeral practices of a particular country or culture; in others, it is a voluntary alternative to burial. It is absolutely essential to remember that any discussion regarding the design and operation of crematoria must bear in mind that the process concerns the disposal of human remains. For this reason, such discussions must be duly dignified, with consideration of the sometimes conflicting relationship between social and cultural requirements and environmental desires.

2. Sources of chemicals listed in Annex C of the Stockholm Convention

The formation and emission of polychlorinated dibenzo-*p*-dioxins (PCDD), polychlorinated dibenzofurans (PCDF), polychlorinated biphenyls (PCB) and hexachlorobenzene (HCB) from cremators is possible due to the presence of these materials, precursors and chlorine in the cadavers and in some co-combusted plastics (e.g. coffin furnishings, which have been phased out in some countries). However, although measurements of PCDD/PCDF have been undertaken from crematoria, there are few or no consistent data for PCB and HCB emissions. Consequently levels of PCB and HCB emissions are much more uncertain than PCDD/PCDF emissions from such sources.

2.1 General information on emissions from crematoria

Airborne emissions consist of nitrogen oxides (NO_x), carbon monoxide (CO), sulphur dioxide (SO₂), particulate matter, metal compounds, including mercury, organic compounds and PCDD/PCDF.

As discussed above, some cremator plant may have air pollution control equipment installed, for example lime and activated carbon injection and fabric filtration. However, most have pollution control ranging from minimal (i.e., a combustion chamber and stack) to reasonably improved systems with secondary combustion chambers and afterburners.

2.2 Emissions of PCDD/PCDF to air

PCDD/PCDF are formed through incomplete combustion or by de novo synthesis when organic and chlorine compounds are present in the feed material or flue gas matrix.

Although it is considered that PCDD/PCDF, PCB and HCB will be destroyed at high temperature (minimum 850°C) in the presence of oxygen, the de novo process of PCDD/PCDF synthesis is still possible if the combustion gases are cooled over an extended period through the reformation temperature window (between 200°C and 400°C). This window can be present in abatement systems, energy recovery equipment and in cooler parts of the furnace, for example the feed area. Care taken in the design of cooling systems to minimize the residence time in the reformation window is practised to prevent de novo synthesis.

In many countries, cremator equipment is often installed in old buildings that are not purpose built. Thus there are often long runs of horizontal ductwork, operating at temperatures within this reformation window. Such systems are also subject to deposition of particulate matter, often containing adsorbed precursors, which enhance the reformation reactions.

In the United Kingdom, for example, cremators are generally required to achieve PCDD/PCDF emission concentrations of less than 0.1 ng I-TEQ/m³ standardized at 11% oxygen, dry and standard temperature and pressure (0°C, 101.3 kPa).¹ However, this is not required to be demonstrated other than by achieving technical combustion

requirements of minimum residence time, temperature and oxygen in the secondary chamber.

An emissions survey of typical cremators was undertaken during discussion of revised regulatory guidance. These tests indicated PCDD/PCDF concentrations ranging between 0.01 and 0.12 ng I-TEQ/m³, and PCB concentrations were low, although limits of detection played a significant role in the estimation of releases.

2.3 Releases to other media

Due to the nature of the process, ashes are an ethical product and are often not subject to any control; spreading of ashes on water, for example, is a potential release route. However, there are often depositions left within the cremator chambers and flueways that are removed during routine maintenance. In the United Kingdom such material is buried at depth within the crematorium grounds (in the same way as metals recovered from the hearth and recovered ashes). A brief study was undertaken for the Federation of British Cremation Authorities and the Cremation Society of Great Britain, which investigated levels of PCDD/PCDF in ashes (Edwards 2001). Levels in the ashes were low enough to be considered insignificant in terms of potential exposure risk.

3. Recommended processes

3.1 Overview

Cremators should be designed to address the requirement for a minimum furnace temperature of 850° C, a 2-second residence time for the combustion gases and sufficient excess air to ensure combustion. The use of designs that cannot achieve these criteria should be discouraged unless demonstrated to be capable of operating without significant emissions of persistent organic pollutants.

Larger facilities, such as may be regulated under the Integrated Pollution Prevention and Control Directive in the European Union, may also have substantial air pollution control requirements to meet emission requirements for other species. These may include, for example, selective non-catalytic reduction for NO_x control, lime injection for acid gas control (SO₂ and HCl), carbon injection for mercury and PCDD/PCDF control and fabric filtration for particulate matter control.

3.2 Best available techniques

Best available techniques are those that consider both technology and management. Control of persistent organic pollutants would comprise the following items and considerations:

- A cremator meeting the minimum temperature, residence time and oxygen requirements and demonstrated to meet those requirements;
- Suitable air pollution control equipment (for control of persistent organic pollutants this would need to include temperature management to control residence time in reformation window, carbon injection and fabric filtration or

equivalent) along with culturally and environmentally appropriate burying of any collected material;

- Combustion chambers and casings should be made as airtight as possible and operate under reduced pressure to minimize release of furnace gases;
- Gas temperatures should be monitored to allow control systems to maintain minimum temperature criteria (through use of support fuel burners) and provide interlocking to stop charge when temperature falls below minimum;
- Flue gas oxygen and carbon monoxide levels should be monitored and linked to the control system to ensure adequate control of air supplies and address any combustion problems;
- Mechanized loading and handling of coffins to minimize exposure to operators;
- Coffin storage facilities to be refrigerated, lockable and rodent and bird proof and have odour control;
- Coffin and coffin fittings should be made of combustible material. Avoid use, or inclusion, of articles containing PVC, metals and other chlorinated compounds;
- Effective operation control, inspection and preventive maintenance of components whose failure could impact on the environment by releasing persistent organic pollutants;
- Operator competencies to be identified and met by suitable training;
- Application of emission limit values and monitoring of emissions to demonstrate emission compliance for persistent organic pollutants.
- Best available techniques for other pollutants have not been considered and it should be recognized that other factors will also impact on the definition of best available techniques for a facility (e.g. water and energy use considerations).

3.3 Best environmental practices

For best environmental practices, countries should aim in the first instance to develop facilities that are capable of meeting the minimum furnace temperature, residence time and oxygen criteria. It should be noted that air pollution equipment may be required to meet local emissions and air quality regulations for pollutants other than persistent organic pollutants.

Where heat recovery or air pollution control equipment is installed then the design of such equipment must address the risk of de novo PCDD/PCDF formation by minimizing the residence time of material in the reformation temperature window. Emissions from such plant should be demonstrated to be free of persistent organic pollutants by measurement on commissioning.

4. Primary and secondary measures

4.1 Primary measures

Primary measures are regarded as pollution prevention techniques to reduce or eliminate the generation and release of persistent organic pollutants. Possible measures include:

4.1.1 Cremator design

The cremator should provide conditions whereby a minimum temperature of 850°C can be maintained throughout charging, burning and ash recovery of the coffin and cadaver with a gas residence time of 2 seconds and sufficient oxygen to ensure destruction of any residual pollutants.

A secondary combustion chamber will be required with afterburners or air injection to meet these criteria. Particular care should be taken to ensure adequate sizing of the secondary chamber and the qualifying volume (the volume downstream of the last injection of fuel or combustion air and with a minimum gas temperature of 850°C throughout the volume). The importance of avoiding cooling of flue gases to temperatures within the reformation window is emphasized.

It is recognized that ash recovery at 850°C will be difficult in small and unmechanized crematoria.

4.1.2 Pre-preparation of cremation

The presence of PVC, metals and other contaminants (particularly chlorine compounds) in the coffin material and furnishings should be avoided to reduce the generation of persistent organic pollutants during incomplete combustion or by de novo synthesis. The correct choice of materials can effectively control emissions of pollutants.

Similarly, placing personal items in the coffin should be avoided or allowed within guidelines to discourage placing of materials in the coffin that would increase the potential for generation of persistent organic pollutants. Crematoria can provide guidelines on (for example) medical implants and items of sentimental value (Australasian Cemeteries and Crematoria Association 2004).

4.1.3 Fuels

Use of waste-derived or other fuels potentially contaminated with persistent organic pollutants should be minimized and must not be used during start-up or process upset when temperatures are below 850°C and unstable conditions may be present. Larger facilities should aim for self-sustaining combustion in the furnace to minimize fuel use.

4.1.4 Effective combustion control

There are three principles at the heart of good combustion control for cremators:

- Maintaining the temperature at the entry and the exit of the secondary chamber at a minimum temperature of 850°C;
- Maintaining the oxygen concentration (and therefore the excess air) within the secondary chamber greater than 6% by volume;
- Holding the combustion gases within the secondary chamber for at least 2 seconds.

4.1.5 Effective process control

Process control systems should be utilized to maintain process stability and operate at parameter levels that will contribute to minimizing generation of persistent organic pollutants, such as maintaining a minimum furnace temperature of 850°C. Variables such as temperature, residence time, and levels of CO, volatile organic compounds and other gas components should be continuously monitored and maintained to establish optimum operating conditions.

4.1.6 Operator competency

The management of the facility is the key to ensuring safe and environmentally benign operation. All personnel operating the facility should be fully conversant with their duties, in particular with regard to routine operation, maintenance, process upset conditions and local environmental legislation. The competency of operators should be addressed by suitable training at an appropriate level for the facility.

4.2 Secondary measures

Secondary measures are pollution control techniques. These methods do not eliminate the generation of contaminants, but serve as means to contain and prevent emissions.

4.2.1 Fume and gas collection

Air emissions should be controlled at all stages of the process, including material handling, combustion and material transfer points, to control the emission of persistent organic pollutants. Sealed furnaces are essential to contain fugitive emissions while permitting heat recovery and collecting off-gases for abatement or discharge. Proper design of hooding and ductwork is essential to minimize fugitive discharge.

4.2.2 Air pollution control equipment

Large facilities should employ a range of air pollution control equipment to provide control for all significant emissions to atmosphere. Care in selection, design and use of air pollution control equipment for other pollutants will also, in general, reduce emissions of persistent organic pollutants. The design has to recognize the potential for de novo formation of selected persistent organic pollutants and minimize the potential for such formation. Particulate matter should be removed to reduce PCDD/PCDF

emissions to atmosphere (although they will be discharged to landfill). Fabric filters are an effective technique but are essentially low-temperature devices (up to 200°C).

Air pollution control operations should be constantly monitored by devices to detect failure. Other developments include online cleaning methods and use of catalytic coatings to destroy PCDD/PCDF.

Activated carbon treatment should be considered for removal of persistent organic pollutants from off-gases. Activated carbon possesses large surface area on which PCDD/PCDF can be adsorbed. Off-gases can be treated with activated carbon using fixed or moving bed reactors, or by injection of powdered activated carbon into the gas stream followed by removal as a filter dust using high-efficiency dust removal systems such as fabric filters.

5. Summary of measures

Tables 1 and 2 present a summary of the measures discussed in previous sections.

Table 1. Measures for recommended processes for crematoria

Measure	Description	Considerations	Other comments
Recommended processes	Large, new installations in developed countries	Minimum 850°C, 2-second residence time in qualifying volume with sufficient air to ensure destruction of persistent organic pollutants. Fit with air pollution control equipment to minimize emissions of SO ₂ , HCl, CO, volatile organic compounds, particulate matter and persistent organic pollutants	These are considered to be best available techniques. Should also have management systems in place, demonstration that facility meets emission limit values and regular monitoring to ensure compliance
	Small installations	Minimum 850°C, 2-second residence time in qualifying volume with sufficient air to ensure destruction of persistent organic pollutants	For smaller plant these conditions should be minimum to address issue of persistent organic pollutants. Could be adopted using a type approval mechanism and inspection of management of facility (rather than expensive emission tests)

■ **Table 2. Summary of primary and secondary measures for crematoria**

Measure	Description	Considerations	Other comments
Primary measures			
Furnace design			Best place to maximize destruction of persistent organic pollutants and minimize their formation
Pre-preparation of cremation	The presence of plastics, metals and chlorine compounds in the coffin material and furnishings should be avoided to reduce the generation of persistent organic pollutants during incomplete combustion or by de novo synthesis	Elimination of chlorinated plastics	Fairly low-tech, but has been successfully implemented in the United Kingdom
Fuel	Clean fuels for support		
Effective combustion control	Technical combustion conditions to meet minimum requirements for temperature, oxygen and residence time	Good combustion results from minimum 850°C, 6% O ₂ and 2 seconds residence time	Requires good design principles and straightforward control techniques to meet requirements
Effective process control	Process control systems should be utilized to maintain process stability and operate at parameter levels that will contribute to the minimization of emission of persistent organic pollutants	PCDD/PCDF emissions may be minimized by controlling other variables such as temperature, residence time, gaseous components	Use of temperature is a fairly basic control parameter. Monitoring of oxygen, CO and volatile organic compounds is more complex but straightforward. However, main issue is maintenance of a control system able to use data in real time to address combustion air supply dampers, support burners and other control features

Measure	Description	Considerations	Other comments
Operator training			In-depth operator training can be provided by cremator manufacturers or trade organizations e.g. Crematorium Technicians Training Scheme in operation in United Kingdom

Secondary measures

Fume and gas collection	Effective containment of furnace gases in all conditions of the cremation process to avoid fugitive releases	Processes to be considered include sealed furnaces to contain fugitive emissions while permitting heat recovery and collecting off-gases	
Air pollution control equipment	Particulate matter abatement will help reduce potential emission of persistent organic pollutants. Activated carbon treatment should be considered as this material possesses large surface area on which PCDD/PCDF can be adsorbed from off-gases	Fabric filtration is the most effective particulate matter abatement and is consistent with use of dry/semi-dry sorbents for acid gas and metals control. However, it will require a temperature reduction. Injection of powdered activated carbon into the gas stream followed by removal as a filter dust	Use of air pollution control devices gives rise to additional waste streams and requires consumables. Likely need to reduce flue gas temperature (to avoid use of more exotic filtration media), consequently care needed to minimize residence in reformation window. Better to avoid formation of persistent organic pollutants in the furnace. However, this approach allows some back-up for process upset conditions and is considered a best available technique in Europe for incineration processes

6. Performance levels associated with best available techniques and best environmental practices

The performance level for air emissions of PCDD/PCDF from crematoria is <0.1 ng I-TEQ/Nm³. For combustion plant, these emission levels are expressed as mass concentrations at 11% oxygen, dry and standard temperature and pressure (0°C, 101.3 kPa). As there is little consistent information available on PCB and HCB emissions from crematoria, it is unclear what emission levels can be achieved for these species.

Data from U.K. crematoria (Edwards 2001) for PCDD/PCDF range between 0.01 and 0.12 ng I-TEQ/Nm³. Data for existing plant in France for PCDD/PCDF range between 0.1 and 4.2 ng I-TEQ/Nm³ (Livolsi et al 2006). The average UNEP result at the Bangkok crematoria (having a long brick flue duct) for PCDD/PCDF was 17.6 ng I-TEQ/Nm³ (Fiedler 2001). A survey of Korean crematoria has reported PCDD/PCDF concentrations of 0.46 to 2.1 ng I-TEQ/Nm³ (Kim et al 2003).

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Notes

- ¹ 1 ng (nanogram) = 1 × 10⁻¹² kilogram (1 × 10⁻⁹ gram). For information on toxicity measurement see section I.C, subsection 3 of the present guidelines.



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