| Category | | Title |
|---|---|---|
| **NFR:** | 5.C.1.b.v | Cremation |
| **SNAP:** | 090901<br>090902 | Incineration of corpses<br>Incineration of carcasses |
| **ISIC:** | | |
| **Version** | Guidebook 2019 | |

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# Contents

# 1 Overview

This chapter covers the atmospheric emissions from the incineration of human bodies in a crematorium and animal carcass incineration.

The contribution of emissions from the incineration of carcasses to the total national emissions is thought to be relatively insignificant (i.e. less than 1 % of the national emissions of any pollutant). The contribution of crematoria to national emissions is comparatively small for all pollutants except for heavy metals (HM), especially mercury, in certain countries. The contribution of this source category to the total emissions of dioxins and furans is reported to be 0.2 % (Oslo and Paris Commission – Environmental Regulations for the European Community (Osparcom)-Helsinki Commission – Baltic Marine Environment Protection Commission (Helcom)-United Nations Economic Commission for Europe (UNECE) Emission Inventory). Crematoria also have the potential to emit polycyclic aromatic hydrocarbons (PAHs), but are unlikely to release significant emissions of other persistent organic pollutants (POPs) (European Topic Centre on Air Emissions (ETC/AEM)-CITEPA-RISOE 1997).

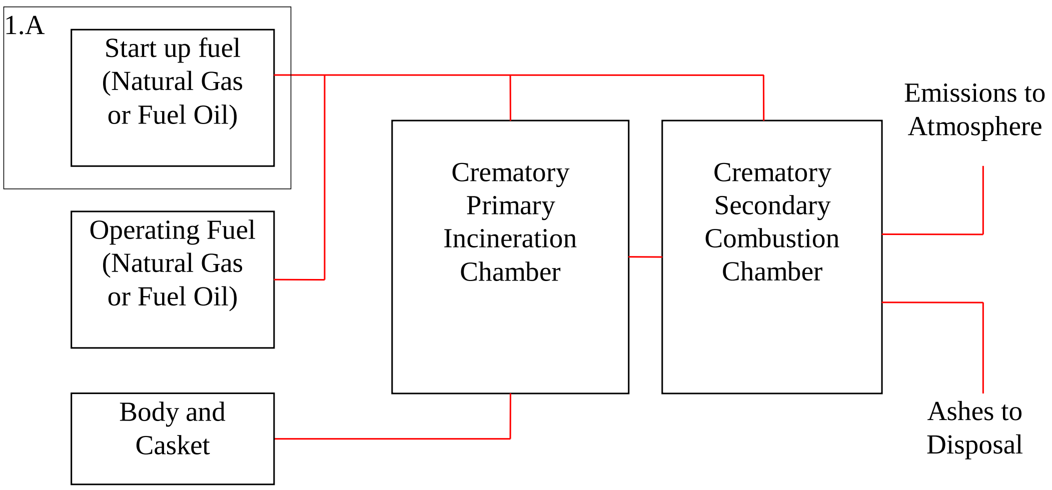
# 2 Description of sources

## 2.1 Process description

There are two main types of crematoria depending on the type of support fuel:

- crematoria using gas or oil as support fuel;
- crematoria using electricity as the support fuel.

**Figure 2-1 Flow diagram of the cremation process showing activities included in this chapter**



Crematories are usually designed with a primary and a secondary combustion chamber (see Figure 2-1). The crematories are usually single-ended units which process one coffin at a time. The coffin is placed inside the primary chamber of the crematory at a temperature of about 300–800 °C. The primary chamber is only preheated by the previous cremation. The secondary chamber, however, is preheated by the support fuel to about 850 °C. This chapter does not cover the emissions from pre-heating.

The primary chamber has burners that are played on the coffin and air lances to break up the remains and promote combustion. The combustion gases from the primary chamber are then fed by a series of ducts into the compartmentalised secondary chamber, which is heated with afterburners and supplied with secondary air to complete combustion and reduce the emissions of carbon-based particulate matter (PM), volatile organic compounds (VOCs), and POPs. The secondary chamber has a residence time for the gases of one to two seconds.

The cremation process begins by placing the body into a specialised cremation casket or cremation container that must be combustible, closed, and resistant to the escape of bodily fluids. The containers may be cardboard, fibreboard, cloth covered fibreboard, or traditional finished wood. This container, with the body enclosed in it, is placed inside the primary cremation chamber.

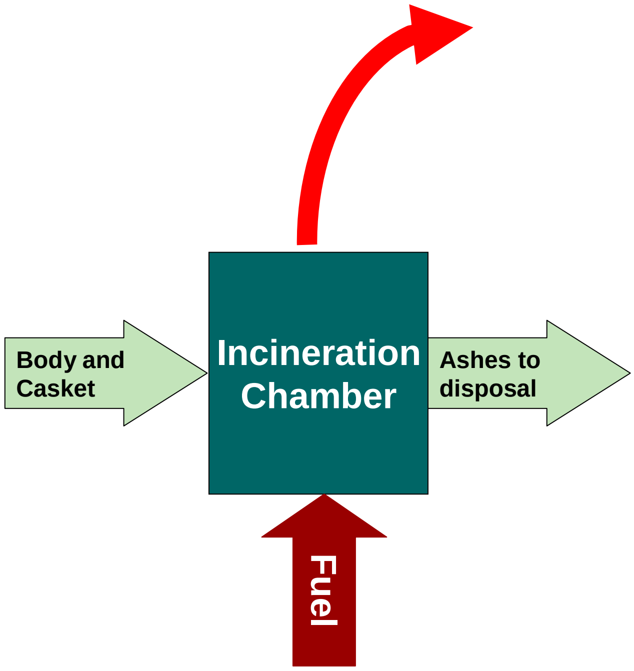
All substances are incinerated and vaporized except for some bone fragments and any non-combustible materials such as prostheses, jewellery, metal hinges, nails, etc. The skeletal framework is reduced to bone fragments and particles (not ashes), called cremated remains.

The time required for the cremation to be completed may vary depending upon the type of cremator and the weight and the size of the person. Generally, cremation time takes between 1.5 and 5 hours, including the cooling period. The cremated remains will weigh approximately four to eight pounds.

Following the cooling period the cremated remains are removed from the chamber using special brushes, rakes, and other equipment. Every effort is made to remove all cremated remains. A small residue may remain inside the cremation chamber and may result in unintentional combining with other cremated remains from previous cremations. All non-combustible matter is separated and removed from the bone fragments by visible and/or magnetic separation. This non-combustible matter will be disposed of by the crematorium in a non-recoverable manner. The bone particles removed from the chamber vary in size and shape and may be mechanically processed to reduce them to a manageable consistency for placement into an urn (Kubasak, 1996).

Ashes are generally mechanically processed to have a more uniform texture and appearance. The incidental fugitive emissions from this processing are negligible.

**Figure 2-2 Process scheme for source category 5.C.1.b.v Cremation**




## 2.2 Techniques

Cremation technology is discussed in (preceding) subsection 2.1 of the present chapter.

## 2.3 Emissions and controls

The major emissions from crematories are nitrogen oxides, carbon monoxide, sulphur dioxide, particulate matter, mercury, non-methane volatile organic compounds (NMVOCs), other heavy metals, and some POPs. The emission rates depend on the design of the crematory, combustion temperature, gas retention time, duct design, duct temperature and any control devices.

Particulates such as dust, soot, ash and other unburned particles originate from the cremation container, human remains, and other contents of the container. Carbon-based organic particulates should be removed in the secondary combustion chamber and through proper adjustment and operation of the cremation equipment.

Carbon monoxide results from the incomplete combustion of the container, human remains, fuel, and other contents. Carbon monoxide may be minimised through proper adjustment and operation of the cremation equipment.

Sulphur dioxide is produced from the combustion of fossil fuels, container, and contents. The sulphur content of natural gas and human remains is low, but other fuels may contain a significant portion of sulphur.

Nitrogen oxides are formed by high temperature combustion processes through the reaction of the nitrogen in air with oxygen. Nitrogen oxide emissions from crematories are low and are not of major concern. Control of nitrogen oxides can be achieved through temperature control and burner design.

Mercury emissions originate from the dental fillings that may contain 5 to 10 grams of mercury depending on the numbers and types used. Mercury may be removed through the use of selenium salt in the cremation chamber (Hogland W., 1994) or scrubbers. It should be noted that in some countries the use of plastic or other types of fillings are gaining popularity which will reduce the mercury emissions.

NMVOCs are produced from incomplete or inefficient combustion of hydrocarbons contained in the fuels, body, and casket. NMVOCs are reduced through the proper use and adjustment of the crematory.

Dioxins and furans result from the combustion of wood cellulose, chlorinated plastics, and the correct temperature range. Dioxins and furans may be reduced through reduction in the chlorinated plastics and with sufficiently high temperature and residence time in the secondary combustion chamber. Reformation of dioxins and furans can be avoided by good design of the flue-gas ducts, by reducing particulate deposition and avoiding the dioxin and furan reformation temperature window.

Most contaminants except for the heavy metals can be minimised through the proper operation of the crematory in conjunction with adequate temperature and residence time in the secondary combustion chamber. Sulphur oxide may be minimised through the use of low sulphur fuels such as natural gas.

Heavy metals except for mercury may be removed through particulate control devices. Mercury can be removed by adding activated carbon to the particulate control devices e.g. bag filters.

Emissions may be further reduced through the use of different types of containers such as fibreboard and cloth-covered fibreboard instead of the traditional finished wood.

With respect to incineration of animal carcasses, the disposal of animal carcasses by methods such as to a licensed incinerator or landfill site is likely to cause significantly less pollution.

# 3 Methods

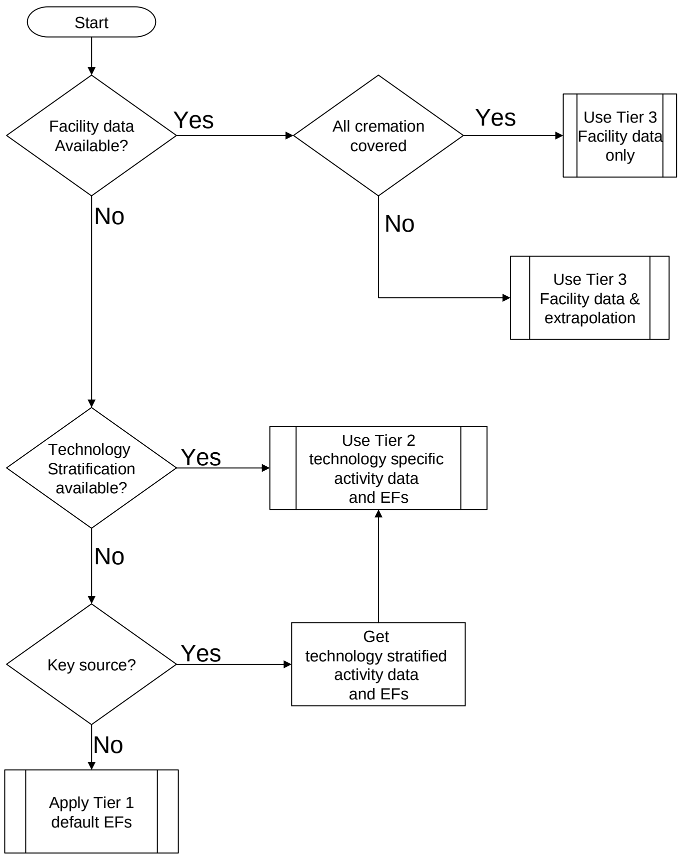
## 3.1 Choice of method

Figure 3-1 presents the procedure to select the methods for estimating emissions from cremation. An equivalent decision tree is applicable to determine emissions for animal carcass incineration. The basic idea is:

- if detailed information is available, use it;
- if the source category is a key category, a Tier 2 or better method must be applied and detailed input data must be collected. The decision tree directs the user in such cases to the Tier 2 method, since it is expected that it is more easy to obtain the necessary input data for this approach than to collect facility-level data needed for a Tier 3 estimate;
- the alternative of applying a Tier 3 method, using detailed process modelling, is not explicitly included in this decision tree. However, detailed modelling will always be done at facility level and results of such modelling could be seen as ‘facility data’ in the decision tree.

This chapter only provides a Tier 1 approach for estimating emissions from cremation. Some Tier 2 emission factors are provided for animal carcass incineration.

**Figure 3-1 Decision tree for source category 5.C.1.b.v Cremation**




## 3.2 Tier 1 default approach

### *3.2.1 Algorithm*

The simpler methodology relies on the use of a single emission factor for each pollutant species, combined with activity statistics. The general equation can be written as:

$$E_{pollutant} = AR_{production} \times EF_{pollutant} \quad (1)$$

This equation uses the cremation activity statistics and the Tier 1 emission factors, provided in the next section.

The Tier 1 emission factors assume an averaged or typical technology and abatement implementation in the country. In cases where specific abatement options are to be taken into account, a Tier 1 method is not applicable and a Tier 2 or Tier 3 approach must be used.

### *3.2.2 Default emission factors*

Table 3-1 presents the Tier 1 default emission factors for cremation for various pollutants from crematory stacks for the cremation of a single body and the container. These emission factors have been derived from all available data and information, taking into account the results of an assessment of emissions factors included in the earlier versions of the Guidebook. Most of the information on the emission factors for this source category is from the US Environmental Protection Agency emission factor database 'WebFIRE'. Information for $NO_x$, CO, NMVOC and $SO_x$ is from an earlier Guidebook version taken from US Environmental Protection Agency (US EPA, 1996) and CANA (1993). Information for PCBs and HCB has been included in the assessment as well.

Where information is available from more than one source, there appear to be large differences in emission factors for some pollutants between the sources, especially PCDD/F is available by many sources and in many different magnitudes. These differences may be attributed to different fuels, design characteristics, or due to the limited testing performed to derive the emission factors.

The emission factors are based on a 55–70 kg body, about 65 kg on average and are for the uncontrolled cremation. Emission factors from US EPA taken from the earlier version of the Guidebook include a 2 kg cardboard and 1 kg wood container, the same applies for US EPA WebFIRE. CANA emission factors are averaged from test data in report for cardboard, cloth-covered and finished wood containers.

Emissions associated with fuel combustion during the cremation are also included in the emission factors. The fuel basis for the cremation emission factors from both the US EPA and CANA are assumed to be natural gas. Emission factors from WebFire (1992) are based on tests from a propane-fired crematorium.

There is a very high uncertainty in the emission factors from cremation, which is affected by:

- the high variability in the operating temperatures;
- the residence time in the secondary combustion chamber;
- the fuels used (fuel oils in Sweden, natural gas in North America).

Large uncertainties and differences may also be caused by different fuels, design characteristics or due to the limited testing performed to derive the emission factors. Especially emissions of mercury can show extremely high variations.

**Table 3-1 Tier 1 emission factors for source category 5.C.1.b.v Cremation, cremation of human bodies**

| Tier 1 default emission factors | | | | | |
|---|---|---|---|---|---|
| | Code | Name | | | |
| **NFR Source Category** | 5.C.1.b.v | Cremation | | | |
| **Fuel** | NA | | | | |
| **Not applicable** | HCH, $NH_3$ | | | | |
| **Not estimated** | BC | | | | |
| | | | **95% confidence interval** | | |
| **Pollutant** | **Value** | **Unit** | **Lower** | **Upper** | **Reference** |
| $NO_x$ | 0.825 | kg/body | 0.0825 | 8.25 | Santarsiero et al. (2005) |
| CO | 0.140 | kg/body | 0.0140 | 1.40 | Santarsiero et al. (2005) |
| NMVOC | 0.013 | kg/body | 0.0013 | 0.13 | CANA (1993) |
| $SO_2$ | 0.113 | kg/body | 0.0113 | 1.13 | Santarsiero et al. (2005) |
| TSP | 38.56 | g/body | 3.856 | 385.6 | WebFIRE, 1992 |
| $PM_{10}$ | 34.70 | g/body | 3.470 | 347.0 | WebFIRE, 1992 |
| $PM_{2.5}$ | 34.70 | g/body | 3.470 | 347.0 | WebFIRE, 1992 |
| Pb | 30.03 | mg/body | 3.003 | 300.3 | WebFIRE, 1992 |
| Cd | 5.03 | mg/body | 0.503 | 50.3 | WebFIRE, 1992 |
| Hg | 1.49 | g/body | 0.149 | 14.9 | WebFIRE, 1992 |
| As | 13.61 | mg/body | 1.361 | 136.1 | WebFIRE, 1992 |
| Cr | 13.56 | mg/body | 1.356 | 135.6 | WebFIRE, 1992 |
| Cu | 12.43 | mg/body | 1.243 | 124.3 | WebFIRE, 1992 |
| Ni | 17.33 | mg/body | 1.733 | 173.3 | WebFIRE, 1992 |
| Se | 19.78 | mg/body | 1.978 | 197.8 | WebFIRE, 1992 |
| Zn | 160.12 | mg/body | 16.012 | 1601.2 | WebFIRE, 1992 |
| PCBs | 0.41 | mg/body | 0.041 | 4.1 | Toda, 2006 |
| PCDD/F | 0.027 | µg/body | 0.0027 | 0.27 | WebFIRE, 1992 |
| Benzo(a)pyrene | 13.20 | µg/body | 1.320 | 132.0 | WebFIRE, 1992 |
| Benzo(b)fluoranthene | 7.21 | µg/body | 0.721 | 72.1 | WebFIRE, 1992 |
| Benzo(k)fluoranthene | 6.44 | µg/body | 0.644 | 64.4 | WebFIRE, 1992 |
| Indeno(1,2,3-cd)pyrene | 6.99 | µg/body | 0.699 | 69.9 | WebFIRE, 1992 |
| HCB | 0.15 | mg/body | 0.015 | 1.5 | Toda, 2006 |

Note: Emission factors from Santarsiero et al. (2005) are calculated from the average of the measured ranges of concentrations, the average flue gas rate (2000-3500 N $m^3$ per h) and the cremation duration (2 h).

### *3.2.3 Activity data*

The statistics required include the number of cremations per year. This information is available from the national statistics agencies, crematorium associations, or may be obtained through direct contact with crematorium operators.

## 3.3 Tier 2 technology-specific approach

For human cremation please refer to the Tier 1 emission factor table. Some emission factors for certain animal incinerations are reported in

Table 3-2 and

Table 3-3.

**Table 3-2 Tier 2 emission factors for source category 5.C.1.b.v Cremation, sheep burn**

| **Tier 2 emission factors** | | | | | |
|---|---|---|---|---|---|
| | Code | Name | | | |
| **NFR Source Category** | 5.C.1.b.v | Cremation | | | |
| **Fuel** | NA | | | | |
| **SNAP (if applicable)** | 090700 | Open burning of agricultural wastes (except 10.03) | | | |
| **Technologies/Practices** | Sheep burn using an air curtain incinerator | | | | |
| **Region or regional conditions** | | | | | |
| **Abatement technologies** | | | | | |
| **Not applicable** | HCH | | | | |
| **Not estimated** | $NO_x$, CO, NMVOC, $SO_2$, $NH_3$, BC, Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB, PCBs | | | | |
| | | | **95% confidence interval** | | |
| **Pollutant** | **Value** | **Unit** | **Lower** | **Upper** | **Reference** |
| TSP | 2.18 | kg/Mg waste | 1.7 | 2.8 | SKM (2005) |
| $PM_{10}$ | 1.53 | kg/Mg waste | 0.153 | 15.3 | Lemieux (2004) |
| $PM_{2.5}$ | 1.31 | kg/Mg waste | 0.131 | 13.1 | Lemieux (2004) |

**Table 3-3 Tier 2 emission factors for source category 5.C.1.b.v Cremation, cow burn**

| **Tier 2 emission factors** | | | | | |
|---|---|---|---|---|---|
| | Code | Name | | | |
| **NFR Source Category** | 5.C.1.b.v | Cremation | | | |
| **Fuel** | NA | | | | |
| **SNAP (if applicable)** | 090700 | Open burning of agricultural wastes (except 10.03) | | | |
| **Technologies/Practices** | Cow burn using an air curtain incinerator | | | | |
| **Region or regional conditions** | | | | | |
| **Abatement technologies** | | | | | |
| **Not applicable** | HCH | | | | |
| **Not estimated** | $NO_x$, CO, NMVOC, $SO_2$, $NH_3$, BC, Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB, PCBs | | | | |
| | | | **95% confidence interval** | | |
| **Pollutant** | **Value** | **Unit** | **Lower** | **Upper** | **Reference** |
| TSP | 0.897 | kg/Mg waste | 0.67 | 1.2 | SKM (2005) |
| $PM_{10}$ | 0.628 | kg/Mg waste | 0.0628 | 6.28 | Lemieux (2004) |
| $PM_{2.5}$ | 0.538 | kg/Mg waste | 0.0538 | 5.38 | Lemieux (2004) |

## 3.4 Tier 3 emission modelling and use of facility data

A Tier 3 method may be performed with varying degrees of accuracy depending on the information that is available. Refinements to the Tier 1 emission factors can be carried out using individual activity statistics (number of bodies cremated), fuel information (quantity and type), control devices, crematory design and types of containers incinerated. Emission testing information can be applied and prorated to other similarly designed crematoriums based on the activity statistics for the facilities.

This method involves obtaining information in increasing detail from the following list:

- activity statistics for each crematorium/crematory,

- design information (operating temperature, control devices, etc.) on the crematory or crematories,
- fuel types and quantities used, and impurities (heavy metals),
- numbers and types of containers incinerated,
- emission testing information.

It is good practice to use the Tier 1 emission factors with the crematory-specific activity data. Emissions testing data will supersede the use of emission factors. It is good practice to use control device information (type, contaminant removal efficiency) in conjunction with emissions testing data or emission factors to enhance the quality of the emissions estimation.

# 4 Data quality

## 4.1 Completeness

Care should be taken to include emissions from waste incineration either in this source category, or in the relevant 1.A combustion chapter. It is good practice to check if this is indeed the case.

## 4.2 Avoiding double counting with other sectors

Care should be taken not do double count emissions from waste incineration. It is good practice to check that emissions not included in this source category (because the heat from the incineration is recovered and the waste is subsequently used as a fuel) are reported in the relevant 1.A combustion chapter.

## 4.3 Verification

### *4.3.1 Best Available Technique emission factors*

No specific document is available describing the Best Available Techniques for cremation. However, the IPPC Reference Document on Best Available Techniques on Waste Incineration (European Commission, 2006) may be used for reference.

## 4.4 Developing a consistent time series and recalculation

No specific issues.

## 4.5 Uncertainty assessment

### *4.5.1 Emission factor uncertainties*

Emission factors have a very high uncertainty, due to the limited testing data available. Uncertainties are also affected by a high variability in operating temperature (650–870 °C), the residence time in the secondary combustion chamber and the fuel used.

Emissions of mercury are directly related to the number and types of dental filling present in the body incinerated. Metal fittings and fastenings on the caskets can affect the emissions of other heavy metals.

#### 4.5.2 Activity data uncertainties

No specific issues.

### 4.6 Inventory quality assurance/quality control QA/QC

No specific issues.

### 4.7 Gridding

Crematoria are mainly found in larger cities; therefore the emissions may be prorated using population statistics.

### 4.8 Reporting and documentation

No specific issues.

# 5 Glossary

| | |
|---|---|
| Crematory | The incineration unit within a crematorium in which the bodies are incinerated and the secondary combustion chamber in the context of this document. |
| Crematorium | The facility which contain the crematory(ies). |
| Cremation chamber | The first chamber within the crematory in which the body is incinerated. |
| Heavy metals | Arsenic, cadmium, chromium, copper, mercury, nickel, lead, selenium, zinc. |
| POPs | Persistent organic pollutants which include dioxins and furans, PAHs (benzo(a)pyrene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene, PCBs (Nos 126, 169, 77, 118, 105, 123, 114, 156, 157, 167, 189), hexachlorobenzene, . |
| Secondary chamber | A second chamber usually containing an afterburner into which exhaust gases from the cremation chamber are fed for odour, PM, and VOC control. |
| Toxic equivalency | (TEQ or I-TEQ) A prioritisation system of the major toxic isomers based on the toxicity of the 2,3,7,8-tetrachlorodibenzo-p-dioxin isomer to allow for the calculation of dioxin and furan emissions in terms of the 2,3,7,8-tetrachlorodibenzo-p-dioxin isomer. |

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# 7 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection's expert panel on combustion and industry. Please refer to the TFEIP website (www.tfeip-secretariat.org/) for the contact details of the current expert panel leaders.