SNAP CODE: **090901**

SOURCE ACTIVITY TITLE: **CREMATION** *Incineration of Corpses*

NOSE CODE: **109.05.01**

NFR CODE: **6 C**

1 ACTIVITIES INCLUDED

This chapter covers the atmospheric emissions from the incineration of human bodies in a crematorium. The emissions associated with the combustion of support fuels during the cremation process are also included (Figure 1).

2 CONTRIBUTION TO TOTAL EMISSIONS

The contribution of this activity to national emissions is comparatively small for all pollutants except for Heavy Metals (HM), especially mercury, in certain countries (Tables 2.1 - 2.2). Hydrogen chloride (HCl) emissions can be significant, although the emissions of HCl from individual crematorium can vary considerably.

There is currently limited information on the emissions of POPs from crematoria. The OSPARCOM-HELCOM-UNECE Emission Inventory indicates that crematoria contribute 0.2 % of the total emissions of dioxins and furans.

Crematoria also have the potential to emit PAHs, but are unlikely to release significant emissions of other POPs or sulphurhexafluoride (SF_6), hydrofluorocarbons (HFCs) or perfluorocarbons (PFCs), (ETC/AEM-CITEPA-RISOE 1997).

Table 2.1: Contribution to the total emissions

Country	SNAP code	Year	Contribution to total Emissions [%]								
			PM	SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3
Canada	090901	1990	0	0	0	0	-	0	-		
Austria	090901	1994	-	0	0	0	0	0	-	0	0
Sweden	090901	1994	-	0	0	0	0	0	-	0	0
Norway	090901	1994	-	0	0	0	0	0	-	0	0
Switzerland	090901	1994	-	0	0.01	0	0	0	-	0	0
France	090901	1994	-	0	0	0	0	0	-	0	0

Table 2.2: Contribution to the total emissions of Heavy Metals

Country	SNAP code	Year	Contribution to total Emissions [%]							
			As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Canada(1)	090901	1990	0	0	0	0	.02	0	0	0
United States(2)	090901	1995			-		0			
Austria(3)	090901	1990	-	-	-	-	.03	-	-	-
Belarus(3)	090901	1990	-	-	-	-	1.1	-	-	-
Belgium(3)	090901	1990	-	-	-	-	.10	-	-	-
Germany(3)	090901	1990	-	-	-	-	.18	-	-	-
Norway(3)	090901	1990	-	-	-	-	4.4	-	-	-
Slovak Republic(3)	090901	1990	-	-	-	-	.02	-	-	-
Spain(3)	090901	1990	-	-	-	-	.005	-	-	-
Sweden(3)	090901	1990	-	-	-	-	20.7	-	-	-
Switzerland(3)	090901	1990	-	-	-	-	.94	-	-	-
United Kingdom(3)	090901	1990	-	-	-	-	5.1	-	-	-

0 = emissions are reported, but, the exact value is below the rounding limit
- = No emissions are reported
(1) Environment Canada, 1997
(2) US - EPA, May 1997
(3) TNO, 1997

Table 2.3: Contribution to total particulate matter emissions from 2004 EMEP database (WEBDAB)†

NFR Sector*	**Data**	**PM_{10}**	**$PM_{2.5}$**	**TSP**
6 C - Waste Incineration	No. of countries reporting	13	11	14
	Lowest Value	0.0%	0.0%	0.0%
	Typical Contribution	1.2%	1.6%	0.8%
	Highest Value	5.8%	7.3%	5.9%

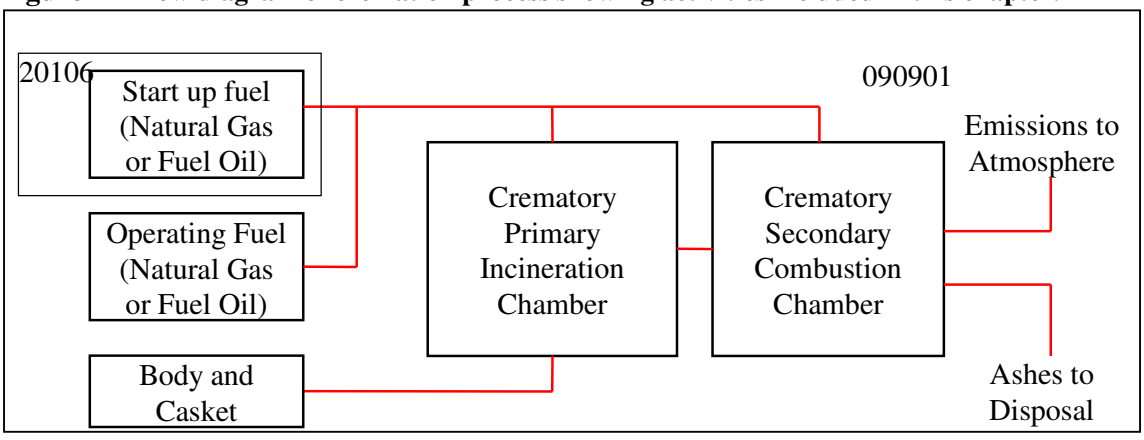
*Includes contribution from Chapters 921, 921, 925, 927 and 970

†These activities are not believed to be a significant source of $PM_{2.5}$ for the majority of countries. Data reported for 2004, however, indicates that it may be significant for in some cases. See relevant chapter B111 supplementary chapter for PM emission factors.

3 GENERAL

3.1 Description

Figure 1 - Flow diagram of cremation process showing activities included in this chapter.



There are 2 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.

Crematories are usually designed with a primary and a secondary combustion chamber (Figure 1). The crematories are usually single ended units which process one coffin at a time. The coffin is placed inside 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), VOCs, and POPs. The secondary chamber has a residence time for the gases of 1 to 2 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, fiberboard, cloth covered fiberboard, 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, jewelry, 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 4 to 8 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 is negligible.

3.2 Definitions

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, zinc.

POPs - Persistent Organic Pollutants which include Dioxins and Furans, PAHs (benzo(a)pyrene, benzo(ghi)perylene, Benzo(k)fluoranthene, Fluoranthene, Indendo(123-cd)pyrene, Benzo(b)fluoranthene, Benz(a)anthracene, Dibenz(ah)anthracene), PCBs (Nos. 126, 169, 77, 118, 105, 123, 114, 156, 157, 167, 189), Hexachlorobenzene, Toxaphene, Chlordane, Aldrin, DDT, Mirex, Dieldrin, Endrin, Hexabromobiphenyl, Pentachlorophenol, Heptachlor, Chlordecone, Short Chain Chlorinated Paraffins (SCCP), Lindane.

Secondary Chamber - A second chamber usually containing an afterburner into which exhaust gases from the cremation chamber are fed for odor, 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.

3.3 Techniques

Cremation technology is discussed in section 3.1

3.4 Emissions and Controls

The major emissions from crematories are nitrogen oxides, carbon monoxide, sulphur dioxide, particulate matter, mercury, hydrogen fluoride (HF), hydrogen chloride (HCl), 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 remove 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.

Hydrogen fluoride and hydrogen chloride results from the combustion of plastics contained in the container and from stomach contents. These hydrogen compounds may be controlled through the use of wet scrubbers. (Cremation Association, 1993)

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, HF, and HCl 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 remove through particulate control devices.

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

4 SIMPLER METHODOLOGY

The simpler methodology of estimating the emissions from crematoriums is to use the cremation activity statistics and the emission factors listed in section 8.1.

N.B There are no emission factors available for $PM_{2.5}$. The source is <0.1% of the total PM emissions for most countries.

5 DETAILED METHODOLOGY

The detailed method may be performed with varying degrees of accuracy depending on the information that is available. Refinements to the emission factors listed in section 8.1, 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.

Should a key source analysis indicate this to be a major source of particulate matter (TSP, PM_{10} or $PM_{2.5}$) then installation level data should be collected using a measurement protocol such as that illustrated in Measurement Protocol Annex.

6 RELEVANT ACTIVITY STATISTICS

6.1 Simpler Methodology

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

6.2 Detailed Methodology

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(ies),
- fuel types and quantities used, and impurities (heavy metals),
- numbers and types of containers incinerated,
- emission testing information.

7 POINT SOURCE CRITERIA

Country emissions from crematoriums contribute only a minor fraction of the total emissions for various contaminants and may be treated as an area source. Crematoriums may also be treated as point sources due to their larger contribution to certain contaminants such as mercury. Treating crematoriums as point sources may become a requirement in the future due to increasing popularity of cremation as a means of disposal over internment due to increasing prices and lower land availability.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Simpler Methodology

Table 8.1 below lists the emission factors and quality codes for various pollutants from crematory stacks for the cremation of a single body and the container. The emissions

associated with the fuel combustion during the cremation is 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.

All emission factors in Table 8.1 have a data quality rating of E.

Toxic Equivalency factors for dioxins and dibenzofurans are presented in Table 8.2. To estimate the emission of dioxins and dibenzofurans in TEQ can be derived by multiplying the calculated emissions for each species by the appropriate TEQ factor and summing the values.

Table 8.1 Emission Factors per Cremation (kg/body)

Pollutant	US-EPA 1996	CANA, 1993	Canada 1996	TNO 1992
Particulate	$2.536x10^{-5}$	$2.239x10^{-1}$		
Sulphur Oxides (SOx)	$5.443x10^{-2}$	$6.364x10^{-2}$		
Nitrogen Oxides (NOx)	$3.085x10^{-1}$	$4.552x10^{-1}$		
Carbon Monoxide (CO)	$1.406x10^{-1}$	$2.121x10^{-1}$		
VOC		$1.30x10^{-2}$		
Arsenic	$1.0977x10^{-8}$			
Cadmium	$3.107x10^{-9}$			
Lead	$1.860x10^{-8}$			
Chromium	$8.437x10^{-9}$			
Mercury	$9.344x10^{-7}$			$5.x10^{-3}$
Nickel	$1.075x10^{-8}$			
Copper	$7.711x10^{-9}$			
Cobalt	$1.633x10^{-9}$			
2,3,7,8-Tetrachlorodibenzo-p-dioxin	$2.077x10^{-14}$			
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	$6.532x10^{-14}$			
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	$7.847x10^{-14}$			
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	$1.134x10^{-13}$			
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	$1.415x10^{-13}$			
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	$1.075x10^{-12}$			
Octachlorodibenzo-p-dioxins, total	$1.710x10^{-12}$			
Tetrachlorodibenzo-p-dioxins, total	$4.019x10^{-13}$			
Pentachlorodibenzo-p-dioxins, total	$6.214x10^{-13}$			
Hexachlorodibenzo-p-dioxins, total	$1.610x10^{-12}$			
Heptachlorodibenzo-p-dioxins, total	$2.309x10^{-12}$			
Polychlorinated dibenzo-p-dioxins, total	$6.668x10^{-12}$			
2,3,7,8-Tetrachlorodibenzofuran	$1.501x10^{-13}$			
1,2,3,7,8-Pentachlorodibenzofuran	$9.117x10^{-14}$			
2,3,4,7,8-Pentachlorodibenzofuran	$2.613x10^{-13}$			
1,2,3,4,7,8-Hexachlorodibenzofuran	$2.708x10^{-13}$			
1,2,3,6,7,8-Hexachlorodibenzofuran	$2.440x10^{-13}$			
1,2,3,7,8,9-Hexachlorodibenzofuran	$4.763x10^{-13}$			
2,3,4,6,7,8-Hexachlorodibenzofuran	$9.798x10^{-14}$			
Heptachlorodibenzofuran-1,2,3,4,6,7,8	$1.397x10^{-12}$			
1,2,3,4,7,8,9-Heptachlorodibenzofuran	$8.573x10^{-14}$			
Octachlorodibenzofurans, total	$4.581x10^{-13}$			
Tetrachlorodibenzofurans, total	$3.130x10^{-12}$			
Pentachlorodibenzofurans, total	$1.842x10^{-12}$			
Hexachlorodibenzofurans, total	$3.107x10^{-12}$			
Heptachlorodibenzofurans, total	$1.642x10^{-12}$			
Polychlorinated dibenzofurans, total	$1.016x10^{-11}$			
Polychlorinated dibenzo-dioxins & -furans	$1.683x10^{-11}$			
Fluoranthene	$5.897x10^{-11}$			
Benzo[a]pyrene	$1.034x10^{-11}$			
Benzo[a]anthracene	$3.778x10^{-12}$			
Hydrogen chloride		0.0159	0.046	
Hydrogen fluoride	$1.873x10^{-7}$			

1. Emission Factors are for a 55 to 70 kg body, about 65 kg on average.
2. No emission control devices were present in the creation of the emission factors
3. US-EPA emission factors include a 2 kg cardboard and 1 kg wood container
4. CANA emission factors averaged from test data in report for cardboard, cloth covered and finished wood containers.

The US-EPA emission factors in Table 8.1 predict significantly lower emissions for particulate than with the CANA or UK emission factors. This difference may be attributed to different fuels, design characteristics, or due to the limited testing performed to derive the emission factors.

Table 8.2 Toxic Equivalency Factors for Dioxins and Dibenzofurans

Dioxin and Dibenzofuran Species	Toxic Equivalency (TEQ)
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1.0
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	0.5
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	0.1
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	0.1
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	0.1
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	0.01
Octachlorodibenzo-p-dioxins, total	0.001
2,3,7,8-Tetrachlorodibenzofuran	0.1
1,2,3,7,8-Pentachlorodibenzofuran	0.05
2,3,4,7,8-Pentachlorodibenzofuran	0.5
1,2,3,4,7,8-Hexachlorodibenzofuran	0.1
1,2,3,6,7,8-Hexachlorodibenzofuran	0.1
1,2,3,7,8,9-Hexachlorodibenzofuran	0.1
2,3,4,6,7,8-Hexachlorodibenzofuran	0.1
1,2,3,4,6,7,8-Heptachlorodibenzofuran	0.01
1,2,3,4,7,8,9-Heptachlorodibenzofuran	0.01
Octachlorodibenzofurans, total	0.001

Table 8.3 TEQ Emission Rates for Dioxins and Furans

Country	Emission (µg I-TEQ/body)	Quality
United Kingdom (APARG, 1995	2.4 - 80	C
Netherlands (Bremmer et al, 1994)	4	C
United States	3.7×10^{-4}	E

The lower emission rate for the United States could be due to differing crematory designs, fuels, or operating temperatures. In the United States crematories appear to operate at higher temperatures than the ones in Sweden and the United Kingdom. The higher temperatures promote the destruction of dioxins and furans.

8.2 Detailed Methodology

The emission factors presented in section 8.1 should be used with the crematory specific activity data. Emissions testing data will supersede the use of emission factors. Control device information (type, contaminant removal efficiency) should be used in conjunction with emissions testing data or emission factors to enhance the quality of the emissions estimation.

9 SPECIES PROFILES

No species profiles currently available

10 UNCERTAINTY ESTIMATES

There is a high degree of uncertainty in the emission factors due to limited testing data available. The uncertainty level is U for unknown / uncertain.

The uncertainty of the emission estimates are also affected by:

- the high variability in the operating temperatures (650 to 870 ^{o}C),
- the residence time in the secondary combustion chamber,
- the fuels used (fuel oils in Sweden to natural gas in North America).

Mercury emissions 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.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The following are some of the aspects for improvement:

- Additional testing for missing emission factors (CO_2, NH_3, etc.).
- Standardisation on reference body weight (e.g. 150 lb. / 68 kg).
- Differing emission characteristics for different container types (cardboard vs. finished wood).
- Information on the effects of different control devices for crematoria.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Crematoriums are mainly found in larger cities and the emissions may be prorated using population statistics.

13 TEMPORAL DISAGGREGATION CRITERIA

Cremation activities are a discontinuous process and may occur at any time of the day or week

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

US - EPA, FIRE Emission Factors Retrieval System version 5.1a, INTERNET: http: // www.epa.gov/ttn/chief/, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 1996

van der Most, P.F.J., Veldt, C., Emission Factors Manual PARCOM-ATMOS Emission Factors for Air Pollutants 1992, Report no. 92-235, TNO, The Netherlands.

16 VERIFICATION PROCESS

Verification of emissions estimation can be done though stack measurements.

17 REFERENCES

ETC/AEM-CITEPA-RISOE (1997) Selected nomenclature for air pollution for CORINAIR94 inventory (SNAP 94), version 0.3 (Draft).

Kubasak, M., The Cremation Process, Cremation Association of North America, INTERNET http://www.cremationinfo.com/, 1996

Cremation Association of North America, Casket and Container Emissions Study (CANA), Paul F. Rahill, Industrial Equipment & Engineering Company, P.O. Box 547796, Orlando, Florida, United States, 1993.

Environment Canada – Pollution Data Branch, Unpublished Heavy Metals Emissions Inventory report, Ottawa, Ontario, Canada, June 1997.

Hogland W.K.H, Usefulness of Selenium for the Reduction of Mercury Emissions from Crematoria, Journal of Environmental Quality, Volume 23, November - December 1994.

TNO Institute of Environmental Sciences, The European Emission Inventory of Heavy Metals and Persistant Organic Pollutants for 1990, Report No. 104 02 672/03, June 1997, Laan van Westenenk 501, P.O. Box 342, 7300 AH Apeldoom, The Netherlands

US - EPA, FIRE Emission Factors Retrieval System version 5.1a, INTERNET: http: // www.epa.gov/ttn/chief/, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 1996.

US - EPA, Locating And Estimating Air Emissions From Sources of Mercury and Mercury Compounds, Office Of Air and Radiation, Office of Air Quality Planning and Standards Research Triangle Park, NC 27711, May 1997.

van der Most, P.F.J., Veldt, C., Emission Factors Manual PARCOM-ATMOS Emission Factors for Air Pollutants 1992, Report no. 92-235, TNO, The Netherlands.

APARG(1995) Report on the Abatement of Toxic Organic Micropollutants (TOMPs) from Stationary Sources 1995. Air Pollution Abatement Review Grou[, DoE, UK. Available form National Environmental Technology Centre, Culham, Abingdon, Oxfordshire, OX14 2DB, UK.

Bremmer, H.J, Troost, L.M., Kuipers, G., de Koning, J. Sein, A.A., Emissions of Dioxins in the Netherlands, Report no. 770501018, National Institute of Public Health and Environmental Protection (RIVM) Bilthoven, The Netherlands, February 1994.

Mitchell, D., Loader, A., Investigation of Pollutant Emissions From Crematoria, Report no. LR 908 (PA), Warren Spring Laboratory, Gunnels Wood Road, Stevenage, Hertfordshire, SG1 2BX, Scotland, February 1993.

Secretary of State's Guidance - Crematoria, Department of the Environment, The Scottish Office, Welsh Office, PG5/2(91).

18 BIBLIOGRAPHY

No additional documents to those in Section 17.

19 RELEASE VERSION, DATE AND SOURCE

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Environment Canada
Canada

Updated with particulate matter details by:
Mike Woodfield
AEA Technology
UK
December 2006

20 POINT OF ENQUIRY

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