WASTE TREATMENT AND DISPOSAL

SNAP CODE : 090201

SOURCE ACTIVITY TITLE : Incineration of Domestic or Municipal Wastes

1 ACTIVITIES INCLUDED

This section includes the volume reduction, by combustion, of domestic and commercial refuse (often referred to as 'Municipal Solid Waste' (MSW)). Principally this section includes the emissions from chimneys and duct work because of the availability of measurement data.

The combustion of hazardous or chemical waste is covered in the chapter on SNAP 090202.

2 CONTRIBUTION TO TOTAL EMISSIONS

The relative proportion of emissions contributed by waste incineration varies between pollutants. The emissions of compounds such as volatile organic compounds (VOCs), sulphur dioxide and hydrogen chloride from waste incineration are unlikely to contribute significantly to total emissions. However waste incinerators have been a major source of emissions of PCDD/Fs, other persistent organic pollutants (POPs) and some heavy metals such as cadmium and mercury (Leech 1993). MSW incinerators in many countries now apply extensive abatement techniques and comply with emission limits, and in these cases the contribution of MSW incinerators to total emissions of PCDD/Fs and heavy metals has greatly decreased.

The CORINAIR90 inventory indicates the contribution of emissions released from the incineration of domestic/municipal waste to total emissions in countries (Table 1).

Table 2.1: Contribution to total emissions of the CORINAIR90 inventory *(up to 28 countries)*

Source-activity	**SNAP-code**	**Contribution to total emissions [%], (including emissions from nature)**							
		SO_2	**NO_x**	**NMVOC**	**CH_4**	**CO**	**CO_2**	**N_2O**	**NH_3**
Incineration of Domestic or Municipal Wastes	**090201**	**0.1**	**0.2**	**0**	**0**	**0.2**	**0.4**	**-**	**-**

0 = emissions are reported, but the exact value is below the rounding limit of 0.1 per cent
- = no emissions are reported

Limited data are available regarding the exact contribution to total emissions of POPs and heavy metals from MSW incineration. Table 2 gives an indication of the contribution of all types of waste incineration to total emissions of heavy metals and POPs.

Table 2.2: Contribution to total POP and heavy metal emissions of the OSPARCOM-HELCOM-UNECE emission inventory *(up to 39 countries)*

Source-activity	**SNAP-code**	**Contribution to total emissions (including emissions from nature) [%]**												
		As	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**	**PCBs**	**PCDD/Fs**	**PAH**	**HCB**	**PCP**
Incineration of Domestic or Municipal Wastes	**090201**	**0.2**	**3.2**	**2.3**	**0.7**	**11**	**0.3**	**1.0**	**2.7**	**0**	**23**	**0**	**0.9**	**0**

Incineration of domestic or municipal wastes is unlikely to be a significant source of sulphurhexafluoride (SF_6), hydrofluorocarbons (HFCs) or perfluorocarbons (PFCs), (ETC/AEM-CITEPA-RISOE 1997).

3 GENERAL

3.1 Description

Municipal solid waste is the unwanted material collected from households and commercial organisations. It consists of a mix of combustible and non-combustible materials; paper, plastics, and quantity produced per person varies with the effectiveness of the material recove food waste, glass, defunct household appliances and other non-hazardous. The composition ry scheme in place and with the affluence of the neighbourhood from which it is collected.

Municipal waste can be incinerated to :
- reduce its volume;
- save landfill space and costs;
- and, increasingly, to recover energy from its combustion, either for district / process heating and/or for electricity generation.

3.2 Definitions

Municipal solid waste (MSW) - a mix of unwanted waste material from households and commercial organisations.

Mass burn units - incinerators which burn waste without any major pre-processing. These are typically fed with excess air. Mass burn waterwall designs have water-filled tubes in the furnace walls that are used to recover heat for production of steam and/or electricity. Mass burn rotary waterwall combustors use a rotary combustion chamber constructed of water-filled tubes followed by a waterwall furnace. Mass burn refractory designs are older and typically do not include any heat recovery.

Modular combustors - similar to mass burn units but are generally pre-fabricated and smaller, and are typically starved air.

Refuse-derived fuel (RDF) combustors - incinerate processed waste (eg waste that has been sorted, shredded, pelletised etc).

Moving grate - a grate on which the waste is burned. Primary air is introduced through the grate and passes through the mass of waste material. The moving grate agitates the waste and promotes thorough distribution of air.

Fluidised bed combustors (FBC) - have a bed of sand or similar inert material which is agitated or ‘fluidised’ by an upward flow of air through a porous plate below it. Combustion occurs within the bed. MSW is only burned if it has been sorted or shredded (ie as RDF)

Rotary kiln - waste is fed into a slightly inclined, rotating, refractory-lined drum which acts as a grate surface. The rotating action of the drum mixes it with air supplied through the walls.

Energy recovery - the removal of heat from the exhaust gases so as to provide heat and/or electricity for use in the plant or elsewhere.

PAHs - polycyclic aromatic hydrocarbons.

PCBs - polychlorinated biphenyls.

PCDD/Fs - polychlorinated dibenzo-para-dioxins and polychlorinated dibenzo furans - a series of chlorinated aromatic compounds, commonly known as ‘dioxins’.

POPs - persistent organic pollutants.

NMVOCs - non-methane volatile organic compounds.

HCB - hexachlorobenzene

Fabric filters - consist of semi-permeable material in the form of bags or sleeves which trap particles and which are mounted in an airtight housing (baghouse) which is divided into a number of sections. Fabric filters are also used as a second stage in acid gas control systems.

Electrostatic precipitators (ESP) - use the principle of electrostatic attraction to remove entrained particles from the flue gases. They consist of rows of discharge electrodes (wires or thin metal rods), through which a high voltage is applied, and which run between an array of parallel rows of metal plates which collect the charged particles.

Wet scrubbers - remove acid gases (eg HCl, HF and SO_2) by washing the flue gases in a reaction tower. Designed to provide a high gas-liquid contact. In the first stage the gases are cooled by water sprays, removing HCl, HF, some particulates and some heavy metals. In the second stage calcium hydroxide or another suitable alkali is used to remove SO_2 and any remaining HCl.

Semi-dry scrubbers / spray absorber systems (spray drying) - make use of an alkaline reagent slurry (usually calcium hydroxide) which is introduced as a spray of fine droplets. The acid gases are absorbed into the aqueous phase on the surface of these droplets and neutralised to form a dry product, which is collected in an electrostatic precipitator or fabric filter.

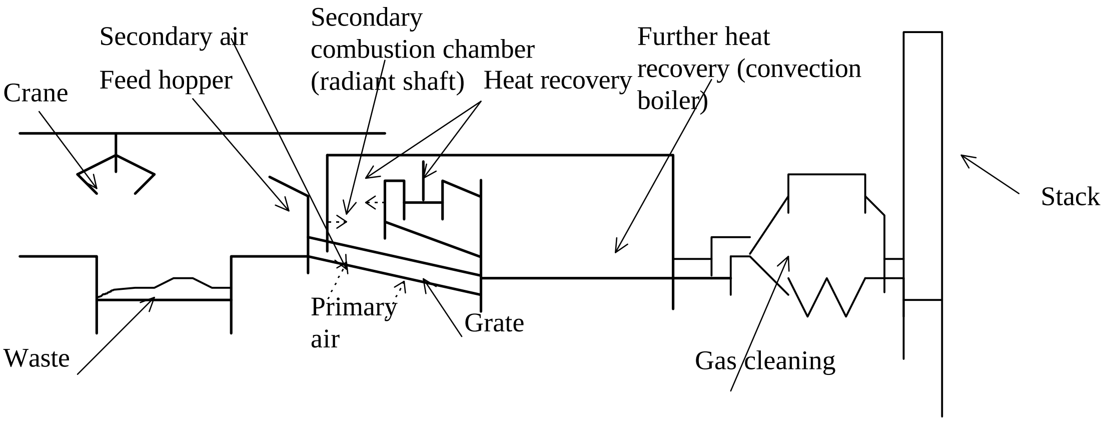
Dry injection systems - involve the injection of an alkaline reagent (eg calcium hydroxide or sodium bicarbonate) as a fine, dry powder to remove and neutralise acid gases. The neutralised product is normally collected in a fabric filter.

Adsorption using activated carbon / activated lignite coke - several different technologies have been developed for dioxin and mercury control. These systems can also be fairly effective at removing HCl and SO_2 and act as a useful polisher for these acid gases.

3.3 Techniques

There are many different furnace designs and combustion techniques in use in Europe for MSW incineration. However the main influences on the total emission expected from these incinerators are the waste burning capacity of the incinerator, the type of incinerator (mass burn excess air or modular starved air), the way in which it is operated (eg whether it includes heat recovery) and the degree of abatement fitted to the plant. Figure 1 shows a simple diagram of the components of a typical MSW incinerator.

Figure 1 - Components of a typical mass burn, excess air MSW incinerator



There are 3 key classes of MSW incineration technology which depend on the quantity and form of the waste burned. These are mass burn units, modular combustors and fluidised bed combustors.

- Mass burn units

  In mass burn units, the MSW is incinerated without any pre-processing other than the removal of items too large to go through the feed system and removal of hazardous items, eg compressed gas cylinders. Mass burn combustors usually range in size from e.g. 45 to 900 tonnes waste/day. Operation of mass burn units typically includes the introduction of excess air. Designs of mass burn combustors include mass burn waterwall, mass burn rotary waterwall combustor, and mass burn refractory wall.

- Modular combustors

  Modular combustors are similar to mass burn combustors as they burn waste that has not been pre-processed, but they are typically shop fabricated and generally smaller, ranging in size from 4 to 130 tonnes waste/day. One of the most common types of modular combustors is the starved air or controlled air type. They are used where start-ups occur each day and/or where throughputs are low, for example at commercial / factory sites or in rural areas.

- Fluidised bed combustors (FBC)

  Fluidised bed combustors have a bed of sand or similar inert material which is agitated or ‘fluidised’ by an upward flow of air through a porous plate below it. Combustion occurs within the bed. For the combustion of MSW in FBC, the fuel has to be treated (eg shredded) in order to obtain a suitable size.

Waste, in whatever form, enters the combustion chamber via the feeder hopper (figure 1). In a typical incinerator, refuse is placed on a grate that moves the waste through the combustor, mixing the waste thoroughly with the hot air to ensure effective combustion. Grate firing installations are capable of burning a range of wastes, which is useful as the composition of the waste varies widely. They can also operate at a range of flow rates. Apart from fluidised bed, there are 2 main types of grate:

- moving grate;
- rotary furnace.

The main combustion technique used for the incineration of MSW is the moving grate. Fluidised bed combustion (FBC) or rotary furnace techniques, have had a more limited use for the incineration of MSW.

Many incinerator designs have two combustion chambers. Air is supplied to the primary chamber through the waste (primary air). The incomplete combustion products (CO and organic compounds) pass into the secondary combustion chamber where additional air (secondary air) is added and combustion is completed.

Incinerator Size

Small incinerator plant with a restricted waste supply are often operated as batch processes. This increases the frequency of start up and burn out emissions which are often excessive.

3.4 Emissions

As well as persistent organic pollutants (eg dioxins), and some heavy metals (eg Pb, Cu, Cd, Cr, Ni, Hg), pollutants released are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOCs and methane (CH_4)), carbon monoxide (CO), carbon dioxide (CO_2), nitrous oxide (N_2O), hydrogen chloride (HCl) and ammonia (NH_3). According to CORINAIR90 (which does not include emissions of dioxins and heavy metals), the main pollutants are NO_x, CO and CO_2 (see also table 1).

Carbon monoxide emissions result when carbon in the waste is not oxidised to carbon dioxide (CO_2). High levels of CO indicate that the combustion gases were not held at a sufficiently high temperature in the presence of oxygen (O_2) for a long enough time to convert CO to CO_2. Because O_2 levels and air distributions vary among combustor types, CO levels also vary among combustor types. Carbon monoxide concentration is a good indicator of combustion efficiency, and is an important criterion for indicating instabilities and non-uniformities in the combustion process (EPA 1995).

Nitrogen oxides are products of all fuel/air combustion processes. Nitric oxide (NO) is the primary component of NO_x; however, nitrogen dioxide (NO_2) and nitrous oxide (N_2O) are also formed in smaller amounts. Nitrogen oxides are formed during combustion through oxidation of nitrogen in the waste, and oxidation of atmospheric nitrogen. Conversion of nitrogen in the waste occurs at relatively low temperatures (less than 1,090 °C), while oxidation of atmospheric nitrogen occurs at higher temperatures. Because of the relatively low temperatures at which municipal waste furnaces operate, 70 to 80 percent of NO_x formed in municipal waste furnaces is associated with nitrogen in the waste.

A variety of organic compounds, including chlorobenzenes, polychlorinated biphenyls (PCB), chlorophenols, polycyclic aromatic hydrocarbons (PAH) and PCDD/Fs are present in MSW or can be formed during the combustion and post-combination processes. Organics in the flue gas can exist in the vapour phase or can be condensed or absorbed on fine particulates.

3.5 Controls

The level of abatement at an incinerator plant varies, depending on the size of the plant, emission regulations etc.

Modern plant, and many older plant which have been updated, have a range of different emission abatement equipment which aim to ensure compliance with emission regulations and address the three main environmental impacts of waste incineration: acid gas, heavy metal and dioxin emissions. Typical approaches used include:

- fabric filters (particle control);
- electrostatic precipitators (particle control);

- wet scrubbers (acid gas removal);
- semi-dry scrubbers / spray absorber systems (acid gas removal);
- dry injection systems (acid gas removal);
- adsorption using activated carbon / activated lignite coke (PCDD/F and mercury removal).

These control systems are described in section 3.2. They are commonly needed in combination; the fabric filter has a secondary function for acid gas control and similarly the wet scrubber for particle control.

NO_x emissions are controlled by using primary or secondary measures as described in the chapter B111 (Combustion Plant).

In the past, many small incinerators have had negligible emission control equipment and the older large plant have had particle control only, frequently by electrostatic precipitator. This abates emissions of heavy metals but may increase the PCDD/F emissions over unabated plant. Older plant also have less ash burn out as the waste combustion is less efficient and this reduces the carbon dioxide emission factor. Although later decay of the ash may lead to carbon dioxide and VOC emission this has not been considered here.

4 SIMPLER METHODOLOGY

The simpler methodology relies on the use of a single emission factor for each pollutant species combined with a national waste incineration statistic:

Total emission = mass of waste incinerated (tonnes) x overall emission factor (emission per tonne of waste incinerated) (1)

A typical emission factor for MSW incinerators within a country can be estimated from the emission factors given in section 8 combined with knowledge of the typical level of abatement and its efficiency :

Typical overall emission factor = baseline emission factor (uncontrolled) x (1 - overall abatement efficiency) (2)

5 DETAILED METHODOLOGY

The detailed methodology involves the use of plant specific emission factors calculated from regulatory emission measurement programmes required, for example, by the EC Directives on MSW incineration, and also using plant specific throughput data normally obtained by each plant. The detailed method will therefore involve the use of a similar equation to the one in section 4, but the equation will be plant specific.

6 RELEVANT ACTIVITY STATISTICS

6.1 Simpler methodology

For the simpler methodology the national annual incineration of waste if required. In addition, a more reliable estimate can be made if information is available on the typical levels of abatement technology used and on the associated overall abatement efficiency.

6.2 Detailed methodology

The more detailed method requires information on plant specific waste throughput and abatement technology, obtained from the operators. There is normally a record kept of tonnage burnt as incinerator operators charge waste generators on that basis.

If neither of these values are available the mass burn rate of each incinerator should be multiplied by an estimated operating time.

7 POINT SOURCE CRITERIA

Within Europe there is a range of incinerator size distributions. In the UK and Germany, for example, the majority of plant are over 10 tonne per hour capacity and there are a limited number of sites in operation. Hence it is possible to treat those incinerators over 5 tonne waste per hour as point sources.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Simpler Methodology

Tables 8.1 to 8.14 give default emission factors where available for :

- an older plant with limited abatement;
- an older plant with particle abatement only;
- a modern plant with particle and acid gas abatement.

The details of these emission factors are given in a Annex 1 and should be referred to by users of this Guidebook chapter.

Table 8.1 - Default Emission Factors[1] for SO_2

Compound	Plant type	Emission factor	Data Quality	Abatement type
SO_2	Older plant	1.7 kg/tonne of MSW	B	Baseline emission factor (uncontrolled)
SO_2	Older plant	1.6 kg/tonne of MSW	D	Particle abatement only
SO_2	Modern plant	0.4 kg/tonne of MSW	C	Particle and acid gas abatement

1. Refer to Table A1.1 in Appendix 1.

Table 8.2 - Default Emission Factors[1] for NOx

Compound	Plant type	Emission factor	Data Quality	Abatement type
NOx	Older plant	1.8 kg/tonne of MSW	C	Baseline emission factor (uncontrolled)
NOx	Older plant	1.8 kg/tonne of MSW	C	Particle abatement only
NOx	Modern plant	1.8 kg/tonne of MSW	C	Particle and acid gas abatement

1. Refer to Table A1.2 in Appendix 1.

Table 8.3 - Default Emission Factors[1] for VOC[2]

Compound	Plant type	Emission factor	Data Quality	Abatement type
NM VOC	Older plant	0.02 kg/tonne of MSW	D	Baseline emission factor (uncontrolled)

1. Refer to Table A1.3 in Appendix 1.
2. Includes CH_4

Table 8.4 - Default Emission Factors[1] for CO

Compound	Plant type	Emission factor	Data Quality	Abatement type
CO	Older plant	0.7 kg/tonne of MSW	C	Baseline emission factor (uncontrolled)
CO	Older plant	0.7 kg/tonne of MSW	C	Particle abatement only
CO	Modern plant	0.5 kg/tonne of MSW	C	Particle and acid gas abatement

1. Refer to Table A1.4 in Appendix 1.

Table 8.5 - Default Emission Factors[1] for N_2O

Compound	Plant type	Emission factor	Data Quality	Abatement type
N_2O	Not given	0.1 kg/tonne of MSW	E	Not given

1. Refer to Table A1.5 in Appendix 1.

Table 8.6 - Default Emission Factors[1] for NH_3

Compound	Plant type	Emission factor	Data Quality	Abatement type
NH_3	Not given	0 kg/tonne of MSW (ie assume negligible emission)	E	Not given

1. Refer to Table A1.6 in Appendix 1.

Table 8.7 - Default Emission Factors[1] for HCl

Compound	Plant type	Emission factor	Data Quality	Abatement type
HCl	Older plant	2.3 kg/tonne of MSW	D	Baseline emission factor (uncontrolled)
HCl	Older plant	2.3 kg/tonne of MSW	D	Particle abatement only
HCl	Modern plant	0.03-0.5 kg/tonne of MSW[2,3]	E	Particle and acid gas abatement

1. Refer to Table A1.7 in Appendix 1.
2. Emission factor depends on type of plant - refer to Table A1.7.
3. Winsey (1997)

Table 8.8 - Default Emission Factors[1] for total particulate matter (PM)

Compound	Plant type	Emission factor	Data Quality	Abatement type
PM	Older plant	18.3 kg/tonne of MSW	C	Baseline emission factor (uncontrolled)
PM	Older plant	0.3 kg/tonne of MSW	C	Particle abatement only
PM	Modern plant	0.05 kg/tonne of MSW	C	Particle and acid gas abatement

1. Refer to Table A1.8 in Appendix 1.

Table 8.9 - Default Emission Factors[1] for lead (Pb)

Compound	Plant type	Emission factor	Data Quality	Abatement type
Pb	Older plant	104 g/tonne of MSW	C	Baseline emission factor (uncontrolled)
Pb	Older plant	23 g/tonne of MSW	D	Particle abatement only
Pb	Modern plant	0.8 g/tonne of MSW	C	Particle and acid gas abatement

1. Refer to Table A1.9 in Appendix 1.

Table 8.10 - Default Emission Factors[1] for cadmium (Cd)

Compound	Plant type	Emission factor	Data Quality	Abatement type
Cd	Older plant	3.4 g/tonne of MSW	D	Baseline emission factor (uncontrolled)
Cd	Older plant	1.2 g/tonne of MSW	D	Particle abatement only
Cd	Modern plant	0.1 g/tonne of MSW	D	Particle and acid gas abatement

1. Refer to Table A1.10 in Appendix 1.

Table 8.11 - Default Emission Factors[1] for mercury (Hg)

Compound	Plant type	Emission factor	Data Quality	Abatement type
Hg	Older plant	2.8 g/tonne of MSW	C	Baseline emission factor (uncontrolled)
Hg	Older plant	2.3 g/tonne of MSW	C	Particle abatement only
Hg	Modern plant	1.1 g/tonne of MSW	D	Particle and acid gas abatement

1. Refer to Table A1.11 in Appendix 1.

Table 8.12 - Default Emission Factors[1] for PCDD/Fs

Compound	Plant type	Emission factor	Data Quality	Abatement type
PCDD/Fs	Not specified	25-1000 µg I-TEQ/tonne of MSW [2]	B	ESP only
PCDD/Fs	Not specified	0.5 µg I-TEQ/tonne of MSW	D	Modern plant (particle abatement plus scrubber with carbon injection)

1. Refer to Table A1.12 in Appendix 1.
2. Recommended emission factor 50 µg I-TEQ/tonne of MSW, depending on operating conditions

Table 8.13 - Default Emission Factors[1] for PCBs

Compound	Plant type	Emission factor	Data Quality	Abatement type
Sum PCBs	Plant type not specified	5.8 mg /tonne of MSW	D	Particle and acid gas abatement
IUPAC No. 77	Plant type not specified	1.6 µg /tonne of MSW	E	Particle and acid gas abatement
IUPAC No. 126	Plant type not specified	1.7 µg /tonne of MSW	E	Particle and acid gas abatement
IUPAC No. 169	Plant type not specified	1.2 µg /tonne of MSW	E	Particle and acid gas abatement

1. Refer to Table A1.13 in Appendix 1.

Table 8.14 - Default Emission Factors[1] for PAHs

Compound	Plant type	Emission factor	Data Quality	Abatement type
Fluoranthene	Poor combustion; plant type not specified	145 mg /tonne of MSW	D	Particle and acid gas abatement
Benz[a] anthracene	Poor combustion; plant type not specified	4.2 mg /tonne of MSW	D	Particle and acid gas abatement
Benzo[bk] fluoranthene	Poor combustion; plant type not specified	6.3 mg /tonne of MSW	D	Particle and acid gas abatement
Benzo[a] pyrene	Poor combustion; plant type not specified	0.7 mg /tonne of MSW	D	Particle and acid gas abatement
Dibenzo[ah] anthracene	Poor combustion; plant type not specified	3.5 mg /tonne of MSW	D	Particle and acid gas abatement

1. Refer to Table A1.14 in Appendix 1.

9 SPECIES PROFILES

The dioxin profile for the relative emissions of the individual isomers measured to make up the Toxic Equivalence does not vary in overall shape between most combustion samples. The profile is dominated by octa chlorinated dioxins and furans.

10 UNCERTAINTY ESTIMATES

Emission factors are likely to vary considerably between different incinerators, depending on the operating conditions and on which of the many combinations of gas cleaning equipment is in use on the plant. The variability at just a single plant for PCDD/Fs, for example, can be an order of magnitude between different sampling periods. Hence any emission factor is subject to an uncertainty considerably greater than a factor of 2.

11 WEAKEST ASPECTS / PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Further work should be invested to develop emission factors, both to reduce the uncertainty of the emission factors in section 8, and to include important pollutants for which no information is available (e.g. other POPs). Improvements to emission factors would be easier if the measurement information collected by national regulatory authorities needs was collated.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

All sources should be considered point sources if greater than 5 tonnes per hour capacity.

13 TEMPORAL DISAGGREGATION CRITERIA

The large incinerators operate as continuously as possible and should be treated as 24 hour 7 days a week emitters. The smaller plant operating at less than 5 tonne per hour should be treated as 8 hour 5 days a week processes unless information available suggests otherwise.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

No supplementary documents are required.

16 VERIFICATION PROCEDURES

Verification is through comparison with emission estimates from different countries together with a measurement programme for selected sites, except for the trace organics as residual historical soil levels may greatly influence present day air concentrations.

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19 RELEASE VERSION, DATE AND SOURCE

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ANNEX 1 - BACKGROUND INFORMATION ON EMISSION FACTORS, QUALITY CODES AND REFERENCES

Table A1.1 - Emission Factors for SO_2

Compound	**Plant type**	**Emission factor**	**Data Quality**	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Country or region**	**Reference** [1]
SO_2	Mass burn excess air combustor	1.7 kg/tonne of MSW	B	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
SO_2	Mass burn excess air combustor	1.4 kg/tonne of MSW	E	Particle abatement only	Not given	MSW	Europe	Holtmann et al. 1995 [2]
SO_2	Mass burn excess air combustor	1.7 kg/tonne of MSW	D	Particle abatement only	Not given	MSW	UK	Clayton et al. 1991
SO_2	Mass burn excess air combustor	0.5 kg/tonne of MSW	D	Dry injection system with ESP	Not given	MSW	USA	US EPA 1995
SO_2	Mass burn excess air combustor	0.3 kg/tonne of MSW	B	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
SO_2	Mass burn excess air combustor	0.7 kg/tonne of MSW	D	Dry injection system with fabric filter	Not given	MSW	USA	US EPA 1995
SO_2	Mass burn excess air combustor	0.1 kg/tonne of MSW	C	Dry injection system with fabric filter	Not given	MSW	EU	Winsey 1997
SO_2	Mass burn excess air combustor	0.3 kg/tonne of MSW	B	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995
SO_2	Mass burn excess air combustor	0.1 kg/tonne of MSW	C	Dry injection system with fabric filter	Not given	MSW	EU	Winsey 1997
SO_2	Modular starved air combustor	1.6 kg/tonne of MSW	E	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
SO_2	Modular starved air combustor	1.6 kg/tonne of MSW	E	ESP	Not given	MSW	USA	US EPA 1995

SO_2	Refuse-derived fuel combustor	2.0 kg/tonne of MSW	D	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
SO_2	Refuse-derived fuel combustor	0.8 kg/tonne of MSW	D	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
SO_2	Refuse-derived fuel combustor	0.2 kg/tonne of MSW	E	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995

1. For emission factors taken from US EPA 1995 (AP-42), data quality ratings have been assumed to be one grade lower than given in the reference because of uncertainty as to whether the emission factors are reliable for European plant.
2. Data quality rating and type of particle abatement not given in reference - assume data quality rating of E.

Table A1.2 - Emission Factors for NOx

Compound	**Plant type**	**Emission factor**	**Data Quality**	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Country or region**	**Reference [1]**
NOx	Mass burn water wall combustor	1.8 kg/tonne of MSW	B	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
NOx	Mass burn water wall combustor	1.8 kg/tonne of MSW	B	ESP	Not given	MSW	USA	US EPA 1995
NOx	Mass burn water wall combustor	2.3 kg/tonne of MSW	C	ESP	Not given	MSW	EU	Winsey 1997
NOx	Mass burn water wall combustor	1.8 kg/tonne of MSW	B	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
NOx	Mass burn water wall combustor	1.8 kg/tonne of MSW	B	Dry injection system with fabric filter	Not given	MSW	USA	US EPA 1995
NOx	Mass burn water wall combustor	1.8 kg/tonne of MSW	B	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995
NOx	Mass burn water wall combustor	2.2 kg/tonne of MSW	C	Spray dryer with fabric filter	Not given	MSW	EU	Winsey 1997

NOx	Mass burn rotary water wall combustor	1.1 kg/tonne of MSW	E	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
NOx	Mass burn rotary water wall combustor	1.1 kg/tonne of MSW	E	ESP	Not given	MSW	USA	US EPA 1995
NOx	Mass burn rotary water wall combustor	1.1 kg/tonne of MSW	E	Dry injection system with fabric filter	Not given	MSW	USA	US EPA 1995
NOx	Mass burn rotary water wall combustor	1.1 kg/tonne of MSW	E	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995
NOx	Modular starved air combustor	1.6 kg/tonne of MSW	C	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
NOx	Modular starved air combustor	1.6 kg/tonne of MSW	C	ESP	Not given	MSW	USA	US EPA 1995
NOx	Refuse-derived fuel combustor	2.5 kg/tonne of MSW	B	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
NOx	Refuse-derived fuel combustor	2.5 kg/tonne of MSW	B	ESP	Not given	MSW	USA	US EPA 1995
NOx	Refuse-derived fuel combustor	2.5 kg/tonne of MSW	B	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
NOx	Refuse-derived fuel combustor	2.5 kg/tonne of MSW	B	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995

1. For emission factors taken from US EPA 1995 (AP-42), data quality ratings have been assumed to be one grade lower than given in the reference because of uncertainty as to whether the emission factors are reliable for European plant.

Table A1.3 - Emission Factors for VOC[1]

Compound	**Plant type**	**Emission factor**	**Data Quality**	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Country or region**	**Reference**
NM VOC	Mass burn excess air combustor	0.02 kg/tonne of MSW	D	Baseline emission factor (uncontrolled)	N/A	MSW	EU	Winsey 1997

[1] Includes CH_4

Table A1.4 - Emission Factors for CO

Compound	Plant type	Emission factor	Data Quality	Abatement type	Abatement efficiency	Fuel type	Country or region	Reference
CO	Mass burn water wall combustor	0.2 kg/tonne of MSW	B	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
CO	Mass burn water wall combustor	0.2 kg/tonne of MSW	B	ESP	Not given	MSW	USA	US EPA 1995
CO	Mass burn water wall combustor	1.1 kg/tonne of MSW	B	ESP	Not given	MSW	UK	Clayton et al. 1991
CO	Mass burn water wall combustor	0.2 kg/tonne of MSW	B	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
CO	Mass burn water wall combustor	0.2 kg/tonne of MSW	B	Dry injection system with fabric filter	Not given	MSW	USA	US EPA 1995
CO	Mass burn water wall combustor	0.04 kg/tonne of MSW	C	Dry injection system with fabric filter	Not given	MSW	EU	Winsey 1997
CO	Mass burn water wall combustor	0.2 kg/tonne of MSW	B	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995
CO	Mass burn water wall combustor	0.1 kg/tonne of MSW	C	Spray dryer with fabric filter	Not given	MSW	EU	Winsey 1997
CO	Mass burn rotary water wall combustor	0.4 kg/tonne of MSW	D	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
CO	Mass burn rotary water wall combustor	0.4 kg/tonne of MSW	D	ESP	Not given	MSW	USA	US EPA 1995
CO	Mass burn rotary water wall combustor	0.4 kg/tonne of MSW	D	Dry injection system with fabric filter	Not given	MSW	USA	US EPA 1995
CO	Mass burn rotary water wall combustor	0.4 kg/tonne of MSW	D	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995

CO	Modular starved air combustor	0.2 kg/tonne of MSW	C	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
CO	Modular starved air combustor	0.2 kg/tonne of MSW	C	ESP	Not given	MSW	USA	US EPA 1995

CO	Refuse-derived fuel combustor	1.0 kg/tonne of MSW	B	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
CO	Refuse-derived fuel combustor	1.0 kg/tonne of MSW	B	ESP	Not given	MSW	USA	US EPA 1995
CO	Refuse-derived fuel combustor	1.0 kg/tonne of MSW	B	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
CO	Refuse-derived fuel combustor	1.0 kg/tonne of MSW	B	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995

1. For emission factors taken from US EPA 1995 (AP-42), data quality ratings have been assumed to be one grade lower than given in the reference because of uncertainty as to whether the emission factors are reliable for European plant.

Table A1.5 - Emission Factors for N_2O

Compound	**Plant type**	**Emission factor**	**Data Quality**	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Country or region**	**Reference**
N_2O	Not given	0.1 kg/tonne of MSW	E	Not given	Not given	MSW	Europe	Holtmann et al. 1995

Table A1.6 - Emission Factors for NH_3

Compound	**Plant type**	**Emission factor**	**Data Quality**	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Country or region**	**Reference**
NH_3	Not given	0 kg/tonne of MSW (ie assume negligible emission)	E	Not given	Not given	MSW	Europe	Holtmann et al. 1995

Table A1.7 - Emission Factors for HCl

Compound	Plant type	Emission factor	Data Quality	Abatement type	Abatement efficiency	Fuel type	Country or region	Reference [1]
HCl	Mass burn excess air combustor	3.2 kg/tonne of MSW	B	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
HCl	Mass burn excess air combustor	3.6 kg/tonne of MSW	E	Particle abatement only	Not given	MSW	Europe	Holtmann et al. 1995 [2]
HCl	Mass burn excess air combustor	3.5 kg/tonne of MSW	C	Particle abatement only	Not given	MSW	UK	Clayton et al. 1991
HCl	Mass burn excess air combustor	0.1 kg/tonne of MSW	D	Dry injection system with ESP	Not given	MSW	USA	US EPA 1995
HCl	Mass burn excess air combustor	0.08 kg/tonne of MSW	B	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
HCl	Mass burn excess air combustor	0.3 kg/tonne of MSW	D	Dry injection system with fabric filter	Not given	MSW	USA	US EPA 1995
HCl	Mass burn excess air combustor	0.1 kg/tonne of MSW	D	Dry injection system with fabric filter	Not given	MSW	EU	Winsey 1997
HCl	Mass burn excess air combustor	0.1 kg/tonne of MSW	B	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995
HCl	Mass burn excess air combustor	0.03 kg/tonne of MSW	D	Spray dryer with fabric filter	Not given	MSW	EU	Winsey 1997
HCl	Modular starved air combustor	1.1 kg/tonne of MSW	E	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
HCl	Modular starved air combustor	1.1 kg/tonne of MSW	E	ESP	Not given	MSW	USA	US EPA 1995

HCl	Refuse-derived fuel combustor	3.5 kg/tonne of MSW	E	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
HCl	Refuse-derived fuel combustor	3.5 kg/tonne of MSW	E	ESP	Not given	MSW	USA	US EPA 1995

1. For emission factors taken from US EPA 1995 (AP-42), data quality ratings have been assumed to be one grade lower than given in the reference because of uncertainty as to whether the emission factors are reliable for European plant.
2. Data quality rating and type of particle abatement not given in reference - assume data quality rating of E.

Table A1.8 - Emission Factors for total particulate matter [1] (PM)

Compound	**Plant type**	**Emission factor**	**Data Quality**	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Country or region**	**Reference [2]**
PM	Mass burn excess air combustor	12.6 kg/tonne of MSW	B	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
PM	Mass burn excess air combustor	0.1 kg/tonne of MSW	B	ESP	Not given	MSW	USA	US EPA 1995
PM	Mass burn excess air combustor	0.5 kg/tonne of MSW	C	ESP	Not given	MSW	UK	Clayton et al. 1991
PM	Mass burn excess air combustor	0.03 kg/tonne of MSW	E	Dry injection system with ESP	Not given	MSW	USA	US EPA 1995
PM	Mass burn excess air combustor	0.04 kg/tonne of MSW	B	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
PM	Mass burn excess air combustor	0.09 kg/tonne of MSW	B	Dry injection system with fabric filter	Not given	MSW	USA	US EPA 1995
PM	Mass burn excess air combustor	0.01 kg/tonne of MSW	C	Dry injection system with fabric filter	Not given	MSW	EU	Winsey 1997
PM	Mass burn excess air combustor	0.03 kg/tonne of MSW	B	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995
PM	Mass burn excess air combustor	0.01 kg/tonne of MSW	C	Spray dryer with fabric filter	Not given	MSW	EU	Winsey 1997

PM	Modular starved air combustor	1.7 kg/tonne of MSW	C	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
PM	Modular starved air combustor	0.2 kg/tonne of MSW	C	ESP	Not given	MSW	USA	US EPA 1995

PM	Refuse-derived fuel combustor	34.8 kg/tonne of MSW	B	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
PM	Refuse-derived fuel combustor	0.5 kg/tonne of MSW	B	ESP	Not given	MSW	USA	US EPA 1995
PM	Refuse-derived fuel combustor	0.05 kg/tonne of MSW	C	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
PM	Refuse-derived fuel combustor	0.07 kg/tonne of MSW	C	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995

1. Total particulate matter as measured with EPA Reference Method 5.

2. For emission factors taken from US EPA 1995 (AP-42), data quality ratings have been assumed to be one grade lower than given in the reference because of uncertainty as to whether the emission factors are reliable for European plant.

Table A1.9 - Emission Factors for lead (Pb)

Compound	Plant type	Emission factor	Data Quality	Abatement type	Abatement efficiency	Fuel type	Country or region	Reference[1]
Pb	Mass burn excess air combustor	107 g/tonne of MSW	B	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
Pb	Mass burn excess air combustor	1.5 g/tonne of MSW	B	ESP	Not given	MSW	USA	US EPA 1995
Pb	Various[2]	45 g/tonne of MSW	D	ESP	Not given	MSW	UK	Clayton et al. 1991
Pb	Mass burn excess air combustor	1.5 g/tonne of MSW	E	Dry injection system with ESP	Not given	MSW	USA	US EPA 1995
Pb	Mass burn excess air combustor	0.5 g/tonne of MSW	B	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
Pb	Mass burn excess air combustor	0.1 g/tonne of MSW	D	Dry injection system with fabric filter	Not given	MSW	USA	US EPA 1995
Pb	Mass burn excess air combustor	0.1 g/tonne of MSW	C	Dry injection system with fabric filter	Not given	MSW	EU	Winsey 1997
Pb	Mass burn excess air combustor	0.1 g/tonne of MSW	B	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995
Pb	Mass burn excess air combustor	0.5 g/tonne of MSW	C	Spray dryer with fabric filter	Not given	MSW	EU	Winsey 1997
Pb	Modular starved air combustor	1.4 g/tonne of MSW	D	ESP	Not given	MSW	USA	US EPA 1995

Pb	Refuse-derived fuel combustor	100 g/tonne of MSW	D	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
Pb	Refuse-derived fuel combustor	1.8 g/tonne of MSW	B	ESP	Not given	MSW	USA	US EPA 1995
Pb	Refuse-derived fuel combustor	0.6 g/tonne of MSW	C	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
Pb	Refuse-derived fuel combustor	0.5 g/tonne of MSW	E	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995

1. For emission factors taken from US EPA 1995 (AP-42), data quality ratings have been assumed to be one grade lower than given in the reference because of uncertainty as to whether the emission factors are reliable for European plant.
2. Emission factor of 45 g/t is mean for measurements carried out at several UK plant before 1991. The emission factor range was 0.4-189 g/t.

Table A1.10 - Emission Factors for cadmium (Cd)

Compound	**Plant type**	**Emission factor**	**Data Quality**	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Country or region**	**Reference** [1]
Cd	Mass burn excess air combustor	5.5 g/tonne of MSW	B	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
Cd	Mass burn excess air combustor	0.3 g/tonne of MSW	C	ESP	Not given	MSW	USA	US EPA 1995
Cd	Various [2]	2.5 g/tonne of MSW	D	ESP	Not given	MSW	UK	Clayton et al. 1991
Cd	Mass burn excess air combustor	0.04 g/tonne of MSW	E	Dry injection system with ESP	Not given	MSW	USA	US EPA 1995
Cd	Mass burn excess air combustor	0.004 g/tonne of MSW	B	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
Cd	Mass burn excess air combustor	0.01 g/tonne of MSW	D	Dry injection system with fabric filter	Not given	MSW	USA	US EPA 1995
Cd	Mass burn excess air combustor	0.01 g/tonne of MSW	C	Dry injection system with fabric filter	Not given	MSW	EU	Winsey 1997

Cd	Mass burn excess air combustor	0.01 g/tonne of MSW	B	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995
Cd	Mass burn excess air combustor	0.01 g/tonne of MSW	C	Spray dryer with fabric filter	Not given	MSW	EU	Winsey 1997
Cd	Mass burn excess air combustor	0.2 g/tonne of MSW	D	Semi-dry scrubber with fabric filter	Not given	MSW	UK	UK NAEI 1997

Cd	Modular starved air combustor	1.2 g/tonne of MSW	E	Baseline emission factor (uncontrolled)	Not given	MSW	USA	US EPA 1995
Cd	Modular starved air combustor	0.2 g/tonne of MSW	E	ESP	Not given	MSW	USA	US EPA 1995

Cd	Refuse-derived fuel combustor	4.4 g/tonne of MSW	D	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
Cd	Refuse-derived fuel combustor	0.1 g/tonne of MSW	D	ESP	Not given	MSW	USA	US EPA 1995
Cd	Refuse-derived fuel combustor	0.04 g/tonne of MSW	E	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
Cd	Refuse-derived fuel combustor	0.02 g/tonne of MSW	B	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995

1. For emission factors taken from US EPA 1995 (AP-42), data quality ratings have been assumed to be one grade lower than given in the reference because of uncertainty as to whether the emission factors are reliable for European plant.

2. Emission factor of 2.5 g/t is mean for measurements carried out at several UK plant before 1991. The emission factor range was 0.01-12.5 g/t.

Table A1.11 - Emission Factors for mercury (Hg)

Compound	Plant type	Emission factor	Data Quality	Abatement type	Abatement efficiency	Fuel type	Country or region	Reference[1]
Hg	Mass burn excess air combustor	2.8 g/tonne of MSW	B	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
Hg	Mass burn excess air combustor	2.8 g/tonne of MSW	B	ESP	Not given	MSW	USA	US EPA 1995
Hg	Various[2]	1.8 g/tonne of MSW	D	ESP	Not given	MSW	UK	Clayton et al. 1991
Hg	Mass burn excess air combustor	2.0 g/tonne of MSW	E	Dry injection system with ESP	Not given	MSW	USA	US EPA 1995
Hg	Mass burn excess air combustor	1.6 g/tonne of MSW	B	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
Hg	Mass burn excess air combustor	1.1 g/tonne of MSW	D	Dry injection system with fabric filter	Not given	MSW	USA	US EPA 1995
Hg	Mass burn excess air combustor	0.1 g/tonne of MSW	C	Dry injection system (with carbon injection) with fabric filter	Not given	MSW	EU	Winsey 1997
Hg	Mass burn excess air combustor	1.1 g/tonne of MSW	B	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995
Hg	Mass burn excess air combustor	0.1 g/tonne of MSW	C	Spray dryer (with carbon injection) with fabric filter	Not given	MSW	EU	Winsey 1997
Hg	Mass burn excess air combustor	0.2 g/tonne of MSW	D	Semi-dry scrubber with fabric filter	Not given	MSW	UK	UK NAEI 1997
Hg	Modular starved air combustor	2.8 g/tonne of MSW	B	Baseline emission factor (uncontrolled)	Not given	MSW	USA	US EPA 1995
Hg	Modular starved air combustor	2.8 g/tonne of MSW	B	ESP	Not given	MSW	USA	US EPA 1995

Hg	Refuse-derived fuel combustor	2.8 g/tonne of MSW	E	Baseline emission factor (uncontrolled)	N/A	MSW	USA	US EPA 1995
Hg	Refuse-derived fuel combustor	2.8 g/tonne of MSW	E	ESP	Not given	MSW	USA	US EPA 1995
Hg	Refuse-derived fuel combustor	2.1 g/tonne of MSW	C	Spray dryer with ESP	Not given	MSW	USA	US EPA 1995
Hg	Refuse-derived fuel combustor	1.5 g/tonne of MSW	E	Spray dryer with fabric filter	Not given	MSW	USA	US EPA 1995

1. For emission factors taken from US EPA 1995 (AP-42), data quality ratings have been assumed to be one grade lower than given in the reference because of uncertainty as to whether the emission factors are reliable for European plant.
2. Emission factor of 1.8 g/t is mean for measurements carried out at several UK plant before 1991. The emission factor range was 0.03-3 g/t.

Table A1.12 - Emission Factors for PCDD/Fs

Compound	**Plant type**	**Emission factor**	**Data Quality**	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Country or region**	**Reference**
PCDD/Fs	Not specified	25-1000 µg I-TEQ/tonne of MSW [1]	B	ESP only	Not given	MSW	EU	Winsey 1997
PCDD/Fs	Not specified	0.5 µg I-TEQ/tonne of MSW	D	Modern plant (particle abatement plus scrubber with carbon injection)	Not given	MSW	EU	Winsey 1997

[1] Recommended emission factor 50 µg I-TEQ/tonne of MSW, depending on operating conditions

Table A1.13 - Emission Factors for PCBs

Compound	Plant type	Emission factor	Data Quality	Abatement type	Abatement efficiency	Fuel type	Country or region	Reference
Sum PCBs	Poor combustion; plant type not specified	5.3 mg /tonne of MSW	D	Multi-step flue gas cleaning [1]	Not given	MSW	Czech Republic	Parma et al. 1995
IUPAC No. 77	Poor combustion; plant type not specified	2.5 µg /tonne of MSW	E	Multi-step flue gas cleaning[1]	Not given	MSW	Czech Republic	Parma et al. 1995
IUPAC No. 126	Poor combustion; plant type not specified	4.1 µg /tonne of MSW	E	Multi-step flue gas cleaning[1]	Not given	MSW	Czech Republic	Parma et al. 1995
IUPAC No. 169	Poor combustion; plant type not specified	1.9 µg /tonne of MSW	E	Multi-step flue gas cleaning[1]	Not given	MSW	Czech Republic	Parma et al. 1995
Sum PCBs	Good combustion; plant type not specified	6.3 mg /tonne of MSW	D	Equipped with one or two step cleaning [2]	Not given	MSW	Czech Republic	Parma et al. 1995
IUPAC No. 77	Good combustion; plant type not specified	0.8 µg /tonne of MSW	E	Equipped with one or two step cleaning [2]	Not given	MSW	Czech Republic	Parma et al. 1995
IUPAC No. 126	Good combustion; plant type not specified	1.2 µg /tonne of MSW	E	Equipped with one or two step cleaning [2]	Not given	MSW	Czech Republic	Parma et al. 1995
IUPAC No. 169	Good combustion; plant type not specified	0.6 µg /tonne of MSW	E	Equipped with one or two step cleaning [2]	Not given	MSW	Czech Republic	Parma et al. 1995

1. e.g. combination of catalytic DeNOx unit, alkaline wet scrubber-venturi, bag filter, coke box
2. e.g. alkaline venturi washer, injection of lime and bag filter

Table A1.14 - Emission Factors for PAHs

Compound	Plant type	Emission factor	Data Quality	Abatement type	Abatement efficiency	Fuel type	Country or region	Reference
Fluoranthene	Poor combustion; plant type not specified	145 mg /tonne of MSW	D	Multi-step flue gas cleaning [1]	Not given	MSW	Czech Republic	Parma et al. 1995
Benz[a] anthracene	Poor combustion; plant type not specified	4.2 mg /tonne of MSW	D	Multi-step flue gas cleaning[1]	Not given	MSW	Czech Republic	Parma et al. 1995
Benzo[bk] fluoranthene	Poor combustion; plant type not specified	6.3 mg /tonne of MSW	D	Multi-step flue gas cleaning[1]	Not given	MSW	Czech Republic	Parma et al. 1995
Benzo[a] pyrene	Poor combustion; plant type not specified	0.7 mg /tonne of MSW	D	Multi-step flue gas cleaning[1]	Not given	MSW	Czech Republic	Parma et al. 1995
Dibenzo[ah] anthracene	Poor combustion; plant type not specified	3.5 mg /tonne of MSW	D	Multi-step flue gas cleaning[1]	Not given	MSW	Czech Republic	Parma et al. 1995

1. e.g. combination of catalytic DeNOx unit, alkaline wet scrubber-venturi, bag filter, coke box

SNAP CODE : 090202

SOURCE ACTIVITY TITLE : Incineration of Industrial Wastes

1 ACTIVITIES INCLUDED

This chapter includes the volume reduction, by combustion, of industrial wastes. The definition of industrial waste varies, but in this case has been assumed to include all non-domestic chemical, hazardous and difficult wastes, and other industrial wastes. In addition the methodology in this chapter includes clinical waste incineration because this source is not covered by any other chapters. Principally this section includes the emissions from chimneys and duct work because of the availability of measurement data, but excludes fugitive emissions from waste handling.

The incineration of domestic/municipal waste is covered under SNAP code 090201 and the incineration of sludges from wastewater treatment is covered under SNAP code 090205. This chapter also does not cover crematoria.

2 CONTRIBUTION TO TOTAL EMISSIONS

The number of large merchant incinerators of hazardous waste, operated by waste disposal contractors to receive a wide variety of wastes from different sources, is relatively small. Many industries have smaller hazardous/chemical waste incinerators constructed within their own site and intended for their use only. A large proportion of these handle only single streams of waste. There is little information on emissions from these smaller plant.

In general, industrial waste incinerators are unlikely to be a significant source of emissions because the waste treated often has a high toxicity and efficient abatement is required to meet the stringent emission standards.

In the UK the large number of small clinical waste incinerators located at hospitals are being replaced by a smaller number of larger-scale centralised incinerators.

The relative proportion of emissions contributed by industrial waste incineration is likely to vary between pollutants. Emissions of carbon dioxide, volatile organic compounds (VOCs) and hydrogen chloride from industrial waste incinerators are likely to be less significant than from other sources. However, industrial waste incinerators are likely to be more significant emitters of dioxins, cadmium and mercury than many other sources, depending on the type of waste, the combustion efficiency and the degree of abatement.

Table 1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**							
		SO_2	**NO_x**	**NMVOC**	**CH_4**	**CO**	**CO_2**	**N_2O**	**NH_3**
Incineration of Industrial Wastes	**090202**	**0.1**	**0**	**0**	**0**	**0**	**0**	**-**	**-**

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

3 GENERAL

3.1 Description

The composition of industrial waste varies considerably. Industrial waste includes any unwanted hazardous/chemical waste such as: acids and alkalis; halogenated and other potentially-toxic compounds; fuels, oils and greases; used filter materials, animal and food wastes. Industrial waste sources include chemical plant, refineries, light and heavy manufacturing etc.

Clinical waste includes human anatomic remains, waste that might be contaminated with bacteria, viruses etc, and general hospital wastes including plastics, textiles etc.

Industrial and clinical waste is incinerated to reduce its volume and to save landfill costs, and to prevent the release of chemical and toxic substances to the environment. In some cases energy is recovered from the waste combustion either for heating or electricity generation.

3.2 Definitions

3.3 Techniques

There are many different furnace designs in use at industrial waste incinerators in Europe. A range of grate designs and fluidised beds are used, but the exact furnace design depends on the type of wastes burned, their composition and the throughput of waste. The principal influences of the incinerator type on the level of atmospheric emissions are the waste burning capacity of the incinerator, the operational techniques and the degree of abatement included in the process design.

Small industrial waste incinerators with a restricted waste supply are often operated as batch processes. This increases the frequency of start up and burn-out emissions, which are often significant.

3.4 Controls

Emissions can be considerably reduced by ensuring efficient combustion, including the control of the temperature, residence time and turbulence in the incinerator furnace. Auxiliary burners and a secondary combustion zone are often included in incinerator designs to ensure effective combustion and burn-out. In addition a range of end-of-process abatement techniques can be applied to reduce emissions. Control of particulates, including heavy metals, can be achieved by fabric filters, electrostatic precipitators or high energy venturi scrubbers. Acid gas emissions can be controlled by wet and dry scrubbing techniques.

4 SIMPLER METHODOLOGY

The simpler methodology relies on the use of a single emission factor for each pollutant combined with a national industrial or clinical waste incineration statistic.

5 DETAILED METHODOLOGY

The detailed methodology involves the use of plant-specific emission factors derived from emission measurement programmes, and plant-specific throughput, normally obtained from each plant.

6 RELEVANT ACTIVITY STATISTICS

For the simpler methodology the national annual quantity of industrial waste incinerated is required.

The more detailed method requires plant specific waste throughput obtained from the operators. A record of quantity burned is normally kept by incinerator operators as waste generators are normally charged on the basis of weight of waste to be burned. If neither of these values are available the mass burn rate of each incinerator should be multiplied by the estimated operating time.

7 POINT SOURCE CRITERIA

There is a range of sizes of industrial waste incinerators within Europe. The larger incinerators may be treated as point sources if plant-specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Emission factors for dioxins have been divided into incinerators meeting modern emission standards and older plant with only particle emission abatement equipment. Separate emission factors have been given for industrial and clinical waste incineration because the type and size of incinerator, and the waste composition, vary greatly for these two types of incinerators. Much of the information on pollutant emissions has been reported as emission concentrations rather than emission factors. These have been converted using a specific flue gas volume of 5000 m^3 at 11% O_2 per tonne of waste.

There is significant uncertainty associated with the aggregation of the reported emissions from different measurement programmes to give a general emission factor. For compounds other than dioxins, the emission factors are given for older plant assuming only particle abatement equipment.

Table 8.1.2: Dioxin Emission Factors for Industrial Waste Incineration Plant

Plant type	**Emission Factor µg I-TEQ/tonne**	**Quality Code**	**Reference**
Particle abatement only	30	C	HMIP (1995) Thomas & Spiro 1994 Fiedler & Hutzinger 1992 Bremmer et al. 1994 Fiedler 1994
Modern advanced	0.5	E	Assumed to be the same as for advanced MSW plant

Table 8.2.2: Typical Emission Factors for Industrial Waste Incineration Plant with only Particle Emission Abatement Equipment

Pollutant	**Emission Factor g/tonne waste burned**	**Quality Code**	**Reference**
SO_2	70	E	1
NOx	2500	E	1
NMVOC	7400	E	Passant 1983
PAH	0.02	D	Wild & Jones 1995 Ramdahl 1982 Mitchell 1992
CO	125	E	1
CO_2	-		
CH_4	-		
HCl	105	E	1
Pb	35	E	1
Cu	3	E	1
Cd	3	E	1
Mn	0.4	E	1
Zn	21	E	1
Co	0.3	E	1
As	0.05	E	1
Cr	0.3	E	1
Ni	0.1	E	1
Hg	3	E	1

[1] Assumed to be the same as for clinical waste incineration (see table 8.4)

Table 8.3: Dioxin Emission Factors for Clinical Waste Incineration Plant

Plant type	**Emission Factor µg I-TEQ/tonne**	**Quality Code**	**Reference**
Particle abatement only	150	C	Mitchell et al. 1992 Mitchell & Scott 1992 Loader & Scott 1992 Cains & Dyke 1993 Thomas & Spiro 1994 Fiedler & Hutzinger 1992
Modern advanced	0.5	E	Assumed to be the same as for advanced MSW plant

Table 8.4: Typical Emission Factors for Clinical Waste Incineration Plant with only Particle Emission Abatement Equipment

Pollutant	**Emission Factor g/tonne waste burned**	**Quality Code**	**Reference**
SO_2	70	D	1,2,3
NOx	2500	D	5
NMVOC	7400	E	9
PAH	0.02	D	6,7,8
CO	125	D	2,3
CO_2	-		
CH_4	-		
HCl	105	C	1,2,3
Pb	35	C	1,2,3,4,5
Cu	3	C	1,2,3,4,5
Cd	3	C	1,2,3,4,5
Mn	0.4	C	1,2,3,5
Zn	21	D	2,3,4
Co	0.3	D	2,3
As	0.05	D	1,2,3,4,5
Cr	0.3	C	1,2,3,4,5
Ni	0.1	C	1,2,3,4,5
Hg	3	C	1,2,3,4

[1] Mitchell et al. 1992

[2] Mitchell & Scott 1992

[3] Loader & Scott 1992

[4] Parcom 1992

[5] US EPA 1985

[6] Wild & Jones 1995

[7] Ramdahl et al. 1982

[8] Mitchell 1992

[9] Passant 1993

9 SPECIES PROFILES

Little data are available on the species profile of dioxin emission from industrial waste incinerators. Emission measurements carried out on clinical waste incinerators have shown that the profile is slightly dominated by the tetra and penta dioxins and furans in terms of toxic equivalence (Mitchell et al. 1992, Mitchell & Scott 1992, Loader & Scott 1992, US EPA 1985)

10 UNCERTAINTY ESTIMATES

The emission factors given are taken from measurements at a wide range of older industrial and clinical waste incineration plant. Little information is available on measurements of emissions from advanced plant. There are wide differences in measured emissions of dioxins and heavy metals depending on both the type of plant and on which of the many combinations of gas-cleaning equipment was in use on the plant. Therefore each emission factor is currently subject to an uncertainty considerably greater than a factor of 2.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The simpler methodology relies on the use of a single emission factor for each pollutant for all plant. However, emission factors for different plant are likely to vary significantly, and the plant-specific detailed methodology is likely to produce a significantly more reliable estimate of total emission. However, plant-specific data are difficult to obtain.

Much of the information on pollutant emissions has been reported as emission concentrations rather than emission factors, and these have been converted using a specific flue gas volume of 5000 m^3 at 11% O_2 per tonne of waste. However, the gas volume per tonne of waste will depend on a number of factors, including the type and throughput of waste, and will therefore vary considerably in reality.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Spatial disaggregation requires the knowledge of the location of industrial waste incinerators. In the absence of such data, disaggregation of national totals should be done on the basis of population.

13 TEMPORAL DISAGGREGATION CRITERIA

Some of the larger industrial and clinical waste incinerators operate as continuously as possible and should be treated as emitters for 24 hour days, 7 days a week. However, the smaller plant with a throughput of less than 5 tonnes per hour should be treated as workday emitters for 8 hour days, 5 days a week, unless any information is available to suggest otherwise.

14 ADDITIONAL COMMENTS

There are many potential problems in estimating emissions, in particular the fact that some countries have more advanced emission abatement programmes for incinerators than other countries.

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

Verification should include comparison with emission estimates from incinerators in other countries together with ambient air measurement programmes near selected sites (except for the trace organics as residual historical soil levels may greatly influence present day air concentrations).

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19 RELEASE VERSION, DATE AND SOURCE

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SNAP CODE : **090203**

SOURCE ACTIVITY TITLE : **Flaring in Oil Refinery**

1 ACTIVITIES INCLUDED

Flares are commonly used during petroleum refining for the safe disposal of waste gases during process upsets (e.g., start-up, shut-down, system blow-down) and emergencies to combust the organic content of waste emission streams without recovering/using the associated energy.

2 CONTRIBUTION TO TOTAL EMISSIONS

Although flaring emission estimates are approximate, total hydrocarbon emissions from flaring at Canadian petroleum refineries during 1988 represented about 0.1% of the refinery sector process and fugitive emissions that also included petroleum marketing emissions (CPPE, 1990). Thus the flaring operation at refineries is estimated to contribute a very small fraction of the total HC emissions in Canada. Emissions from flaring activities may also include: particulate, SOx, NOx, CO and other NMVOC. The CO_2 contribution of both miscellaneous vent and flare emission sources represented approximately 9% of the total petroleum refinery SO_2 emission in Canada during 1988.

Emissions estimates from flaring in petroleum refineries as reported in the CORINAIR90 inventory are summarised in Table 1.

Table 1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**							
		SO_2	**NO_x**	**NMVOC**	**CH_4**	**CO**	**CO_2**	**N_2O**	**NH_3**
Flaring in Petroleum Refineries	**090203**	**0.1**	**0.1**	**0**	**-**	**0**	**0**	**-**	**-**

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

3 GENERAL

3.1 Description

Blowdown systems are used at petroleum refineries (see SNAP Code 0401) to collect and separate both liquid and vapour discharges from various refinery process units and equipment (U.S. EPA 1985, 1992). The gaseous fraction, that may represent a planned or unplanned hydrocarbon discharge, may be either recycled or flared. Flaring provides a widely-used safety mechanism and emission control option for blowdown systems when the heating value of the emission stream cannot be recovered due to uncertain or intermittent releases during process upsets/emergencies. Non-condensed vapours from the blowdown system may be combusted in a flare which is designed to handle large fluctuations of both the flow rate and hydrocarbon content of the discharge. Alternatively, thermal incineration is preferable to flaring for destroying gas releases that contain more corrosive halogenated or sulphur-bearing components.

Although different types of flares exist, the steam-assisted elevated flare systems are most commonly used at petroleum refineries whereby steam is injected in the combustion zone of the flare to provide turbulence and inspirated air to the flame. For waste gases of insufficient heating value, auxiliary fuels may also be used to sustain combustion.

3.2 Definitions

3.3 Techniques

Steam-assisted elevated flares are installed at a sufficient height above the plant and located at appropriate distances from other refinery facilities. The flare generally comprises a refractory flame platform with a windshield, steam nozzles, auxiliary gas/air injectors and a pilot burner mounted upon a stack containing a gas barrier. As reported (U.S. EPA 1980, 1992, MacDonald 1990), the flare combustion efficiency typically exceeds 98% with dependence on the following factors (i.e., for efficient performance):

excess steam assist (i.e., steam/fuel gas ratio less than 2),

sufficient gas heating value (i.e., greater than 10 MJ/m3),

low wind speed conditions (i.e., above 10 m/sec.),

sufficient gas exit velocity (i.e., above 10 m/sec.)

Similarly, different types of flare burners, designed primarily for safety requirements, may result in different efficiencies.

3.4 Emissions/Controls

Depending on the waste gas composition and other factors, the emissions of pollutants from flaring may consist of unburned fuel components (e.g., methane, NMVOC), by-products of the combustion process (e.g., soot, partially combusted products, CO, CO_2, NOx) and sulphur oxides (e.g., SO_2) where sulphur components are present in the waste gas. Steam injection is used to enhance combustion for smokeless burning and to reduce NOx by lowering the flame temperature. Increased combustion efficiency may reduce CH_4 and NMVOC, but will not reduce CO_2 emissions. Flaring emissions might best be reduced by minimising amounts of gases to be flared, provided that the associated wastes gases are not vented directly.

4 SIMPLER METHODOLOGY

Where limited information is available, the simplest inventory methodology is to combine the amounts of gases flared by petroleum refineries with a single hydrocarbon emission factor (i.e., derived in units of mass emission per volume of gas flared), with the assumption of a constant flare combustion efficiency. In the event that flare gas volumes are unavailable, an alternative but older emission estimation methodology would be to apply individual emission factors of various pollutants for petroleum refinery blowdown systems (i.e., including vapour recovery systems and flaring) in combination with total petroleum refinery feed (i.e., crude oil throughput).

5 DETAILED METHODOLOGY

The detailed methodology requires each refinery to estimate its flaring emissions using available information on the composition of flare gas, the types of smoke control used and the flare combustion efficiency in combination with flare gas volumes, using either measurement data, available emission factors or mass balance approaches. It is recognised that flare emissions are challenging to estimate and/or quantify with certainty, since: conventional or direct extractive source testing is not feasible for elevated flares; both flare gas volume determinations and/or gas composition may be very uncertain especially during process upsets or emergency releases; and very limited data are available with respect to flare combustion efficiencies which depend on both process and external wind condition factors. For normal operations, the general types of refinery and other information required to estimate flare emissions, as currently done at Canadian refineries (CPPI 1991), are:

- the actual quantities of gases flared at each flare (e.g. m^3/year) based upon measured flare gas flowmeter or other records,
- the average composition of flare gas including: H/C molar ratio on the basis of flare design or test data, the molecular weight and sulphur content,
- the types of smoke controls used, such as: steam/air, manual/automatic and/or TV monitor,
- an emission HC factor based upon typical steam/fuel gas ratios, gas heating values and/or flare combustion efficiencies,
- a sulphur mass balance of fuels consumed by flaring and other refinery process heaters/boilers.

In some instances, flare emissions may only be estimated currently by difference or rough approximations. However, remote sensing of flare emissions by LIDAR/DIAL measurements of plume cross section seams are assisting in determining or verifying flare emission rates and the composition of refinery flare emissions (Bodon, Moncrieff and Wootton, 1992).

6 RELEVANT ACTIVITY STATISTICS

For the simpler methodology, either the quantities of flare gases consumed or the refinery crude oil feed is required. For more detailed methodology, the quantities, composition and heating values of flare gases burned are required for each petroleum refinery.

7 POINT SOURCE CRITERIA

All significant refinery flares are to be inventoried as part of refinery point sources.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Only limited published petroleum refinery flare emission factors are available. For the simpler methodology, somewhat dated emission factors have been reported (U.S. EPA, 1985) as in Table 2.

Table 2: Emission Factors for Flaring in Petroleum Refineries

Process	**Emission Factors (kg 10^3 litres refinery feed)**					Rating
	Particulate	SO_2	CO	THC	NOx	
Refinery Blowdown System - Vapour Recovery System and Flaring	Neg.	0.077	0.012	0.002	0.054	C

In the current U.S. EPA CHIEF database, the VOC emission factor for petroleum refinery flares is: 5.6 lb VOC/million cubic feet of flare gas burned with a quality rating of D. The above mentioned VOC emission factor comprises: methane (20%), ethane (30%), propane (30%) and formaldehyde (20%).

A VOC emission factor, reported in a Norwegian survey (OLF Report Phase 1, Part A), of 0.0095 kg/m3 of flare gas was cited in documentation of the UNECE Task Force - VOC Emissions from Stationary Sources. The flare emissions were reported to consist of 65% methane and 35% NMVOC and suggested a typical flare efficiency of 99.2%.

Remote sensing (DIAL) measurements of full-sized flare emissions at a Norwegian petroleum refinery under normal operating conditions also has indicated that the flare combustion efficiency exceeded 98%, comprising various amounts of methane and C2 to C6+ alkane components (Boden, Moncrieff and Wootton, 1992).

Flare combustion efficiencies, under atypical operating or other conditions and presumably during upset conditions, may have lower destruction efficiencies, based upon other test data (MacDonald 1990).

9 SPECIES PROFILES

(See section 8).

10 UNCERTAINTY ESTIMATES

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

As flare emissions can vary significantly with dependence on several factors, more measurements to determine flare combustion efficiencies and chemical composition should be done (e.g., perhaps using remote sensing techniques) under a variety of conditions, in order to verify available emission estimates and assure that flare combustion efficiencies generally represent the stated efficiencies.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

13 TEMPORAL DISAGGREGATION DATA

No temporal apportionment of these emissions is possible if the simpler methodology is used. Temporal disaggregation of detailed emission estimates can be done from records of petroleum refinery shutdowns and other operating data.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

As noted above, remote sensing monitoring programs may be useful to verify flaring emission estimates.

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19 RELEASE VERSION, DATE AND SOURCE

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SNAP CODE :	**090204** **090208**
SOURCE ACTIVITY TITLE :	**Flaring in Chemical Industries** **Incineration of Waste Oil**

A specific methodology for these activities has not been prepared because the contribution to total national emissions is thought to be currently insignificant, i.e. less than 1% of national emissions of any pollutant.

If you have information contrary to this please contact the expert panel leaders.

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SNAP CODE : **090205**

SOURCE ACTIVITY TITLE : **Incineration of Sludges from Water Treatment**

1 ACTIVITIES INCLUDED

This chapter includes the volume reduction, by combustion, of sludge resulting from municipal waste water treatment (sewage). Principally this section includes the emissions from chimneys and duct work but not the fugitive emissions from residue handling.

2 CONTRIBUTION TO TOTAL EMISSIONS

The number and throughput of sewage sludge incinerators are small and hence they are rarely a significant source of pollutants except on a local scale. Emissions estimates from incineration of sludges from water treatment as reported in the CORINAIR90 inventory are less than 0.1%.

In the UK dioxin emissions from sewage sludge incineration are likely to contribute up to 0.6% of the total UK dioxin emissions at present.

3 GENERAL

3.1 Description

Sewage sludge arises from two principal sources (HMIP 1992):

- The removal of solids from raw sewage. This primary sludge has a solids content of about 5% and consists of both organic and inorganic substances.
- The removal by settlement of solids produced during biological treatment processes i.e. surplus activated sludge and human sludge. This is known as secondary sludge.

Sewage sludge is incinerated to reduce its volume to lower disposal costs and, in some instances, to recover energy from its combustion either for heating or electricity generation.

3.2 Definitions

3.3 Techniques

At all operational plants the wet sludge is de-watered prior to incineration (HMIP 1992). Several dewatering processes are available; centrifuges, belt or plate presses.

There are three main designs of furnace used for sludge incineration; rotary kiln, fluidised bed and multiple hearth. However the principal influence on the emission factors applicable to a plant is the degree of pollution abatement equipment fitted to the plant.

Virtually any material, that can be burned, can be combined with sludge in a co-incineration process. Common materials for co-combustion are coal, municipal solid waste (MSW), wood waste and agriculture waste. Thus, municipal or industrial waste can be disposed of while providing a self-sustaining sludge feed, thereby solving two disposal problems. There are two basic approaches to combusting sludge with MSW: use of MSW combustion technology by adding dewatered or dried sludge to the MSW combustion unit, and use of sludge combustion technology by adding processed MSW as a supplemental fuel to the sludge furnace (EPA 1994).

- Fluidised Bed Furnace
  FBC consist of vertically oriented outer shell constructed of steel and lined with refractory. Nozzles (designed to deliver blasts of air) are located at the base of the furnace within a refractory-lined grid. A bed of sand, approximately 0.75 meters thick, rests upon the grid. Two general configurations can be distinguished on the basis of how the fluidising air is injected into the furnace. In the “hot windbox” design the combustion air is first preheated by passing through a heat exchanger where heat is recovered from the hot flue gases. Alternatively, ambient air can be injected directly into the furnace from a cold windbox. Partially dewatered sludge is fed into the lower portion of the furnace. Air injected through the nozzles simultaneously fluidises the bed of hot sand and the incoming sludge. Temperatures of 750 to 925 °C are maintained in the bed. As the sludge burns, fine ash particles are carried out the top of the furnace (EPA 1994).

  A fluidised bed incinerator is a single stage process. Examples of the advantages of fluidised bed incinerators include the disposal of solids, liquids, aqueous waste and gases, and the simplicity of the furnace with no moving parts. Disadvantages include the fact that bed diameters and height are limited by design technology and high levels of dust carryover in the flue gas (HMIP 1992).

- Multiple hearth furnace
  The design principle of a multiple hearth furnace (MHF) is a vertical cylinder. The outer shell is constructed of steel, lined with refractory, and surrounds a series of horizontal refractory hearths. Burners, providing auxiliary heat, are located in the sidewalls of the hearths (EPA 1994).

  Scum may also be fed to one or more hearths of the incinerator. Scum is the material that floats on wastewater. It is generally composed of vegetable and mineral oils, grease, hair, waxes, fats, and other materials that will float. Quantities of scum are generally small compared to those of other wastewater solids (EPA 1994).

  Under normal operating condition, 50 to 100 % excess air must be added to a MHF in order to ensure complete combustion of the sludge. Besides enhancing contact between fuel and oxygen in the furnace, these relatively high rates of excess air are necessary to compensate for normal variations in both the organic characteristics of the sludge feed and the rate at which it enters the incinerator. When an inadequate amount of excess air is available, only partial oxidation of the carbon will occur, with a resultant increase in emissions of carbon monoxide, soot, and hydrocarbons. Too much excess air, on the other hand, can cause increased entrainment of particulate and unnecessarily high auxiliary fuel consumption (EPA 1994).

MHF may be operated with an afterburner. The advantages of multiple hearth furnace incinerators include the fact that the retention and residence time is higher for low volatility materials than in other types of incinerator, the handling of high water content wastes and of a wide range of wastes with different chemical and physical properties. Disadvantages include the fact that, due to the longer residence times of the waste materials, temperature response throughout the incinerator when the burners are adjusted is usually very slow, variations in feed can alter the temperature profile and thus the positions of the zones, and difficulties in achieving complete oxidation of volatile organic materials placing an additional load on an afterburner can occur (HMIP 1992).

- Other kiln types
  Rotary kilns are used for small capacity applications. The kiln is inclined slightly with the upper end receiving both the sludge feed and the combustion air. A burner is located at the lower end of the kiln (EPA 1994).

  Electric infrared incinerators consist of a horizontally oriented, insulated furnace. A woven wire belt conveyor extends the length of the furnace and infrared heating elements are located in the roof above the conveyor belt. Combustion air is preheated by the flue gases and is injected into the discharge end of the furnace. Electric infrared incinerators consist of a number of prefabricated modules, which can be linked together to provide the necessary furnace length (EPA 1994). The use of electric infrared furnaces is not so common (EPA 1995).

  The cyclonic reactor is designed for small capacity applications. It is constructed of a vertical cylindrical chamber that is lined with refractory. Preheated combustion air is introduced into the chamber tangentially at high velocities. The sludge is sprayed radially towards the hot refractory walls (EPA 1994).

The wet oxidation process is not strictly one of incineration; it instead utilises oxidation at elevated temperature and pressure in the presence of water (flameless combustion). Thickened sludge, at about 6 % solids, is first ground and mixed with a stoichiometric amount of compressed air. The slurry is then pressurised. The mixture is then circulated through a series of heat exchangers before entering a pressurised reactor. The temperature of the reactor is held between 175 and 315 °C. Steam is usually used for auxiliary heat. Off-gases must be treated to eliminate odours: wet scrubbing, afterburning or carbon absorption may be used (EPA 1994).

Abatement Equipment

The options available for acid gas removal include spray drying and wet or dry scrubbing. Where the emission levels of nitrogen oxides are high, due to the design of the incinerator or because of co-incineration of wastes, urea can be injected into the flue gases to reduce oxides of nitrogen levels by about 30 % (HMIP 1992).

The exhaust gases of the furnaces containing volatile compounds are taken through an afterburner or similar combustion chamber to ensure complete combustion of residual organic material in the vent gas, and to prevent the emission of smoke and odour (HMIP 1992).

As there is the possibility of the formation of dioxins/furans, between 200 and 450 °C, it is important that when gases are cooled it is done as rapidly as possible through this critical temperature range. Such cooling may be accomplished by the use of a heat exchanger/waste heat boiler (of special design) or water spray cooling (HMIP 1992).

In general, older plants have particle arrestment, frequently using an electrostatic precipitator. This will abate the emissions of heavy metal species but may increase dioxin emissions. Modern plant or older plant which have been updated, have a range of different emission abatement equipment which addresses the three main environmental impacts of sewage sludge incineration; acid gas, heavy metal and dioxin emissions.

Typical units fitted include fabric filters, wet scrubbers, lime slurry spray dryer towers, carbon injection with the lime to control mercury and dioxins and activated carbon or coke beds.

3.4 Emissions

Pollutants released are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOC and methane (CH_4)), carbon monoxide (CO), carbon dioxide (CO_2) and nitrous oxide (N_2O). According to CORINAIR90 no main relevant pollutant can be separated (see also Table 1), due to the low contribution of incineration plants of sludge from waste treatment to total emissions.

However, sewage sludge incinerators potentially emit significant quantities of pollutants on a local basis. Major pollutants emitted are: particulate matter, metals, CO, NO_x, SO_2, and unburned hydrocarbons. Partial combustion of sludge can result in emissions of intermediate products of incomplete combustion, including toxic organic compounds such as dioxins (EPA 1994, 1984, 1979, 1982).

Nitrogen and sulphur oxide emissions are primarily the result of oxidation of nitrogen and sulphur in the sludge. Therefore, these emissions can vary greatly based on local and seasonal sewage characteristics (EPA 1995).

Emissions of volatile organic compounds also vary greatly with incinerator type and operation. Incinerators with countercurrent air flow such as multiple hearth designs provide the greatest opportunity for unburned hydrocarbons to be emitted (EPA 1995).

Carbon monoxide is formed when available oxygen is insufficient for complete combustion or when excess air levels are too high, resulting in lower combustion temperatures (EPA 1995).
Polycyclic organic matter emissions from sewage sludge incineration potentially originate from the combustion of carbonaceous material in the sludge, from the combustion POM precursors that may exist in the sludge, and from the combustion of supplemental incinerator fuel (typically natural gas or fuel oil) (EPA 1994).

4 SIMPLER METHODOLOGY

The simpler methodology relies on the use of a single emission factor for each pollutant species combined with a national sludge incineration statistic.

5 DETAILED METHODOLOGY

The detailed methodology involves the use of plant-specific emission factors calculated from emission measurement programmes and plant-specific throughput information obtained from each plant.

6 RELEVANT ACTIVITY STATISTICS

For the simpler methodology the national annual incineration of sewage sludge is required.
The more detailed method requires plant-specific waste throughput obtained from the operators.

If neither of these values are available the mass burn rate of each incinerator should be multiplied by an estimated operating time.

7 POINT SOURCE CRITERIA

The number of sewage sludge incinerators is small so that they may be treated as point sources if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Table 2 contains sludge-related emission factors for incineration of sludge from waste treatment based on CORINAIR90 data in g/GJ. Technique-related emission factors, mostly given in other units (e.g. g/Mg product), are listed in footnotes. The lower heating value depends strongly on the composition of sludge and the content of water: At this stage no data are available for an appropriate definition of a range of lower heating values within the literature.

Table 2: Emission factors for incineration of sludge from waste treatment

			Emission factors						
	Fuel	**NAPFUE-code**	**SO_2 2) [g/GJ]**	**NO_x 3) [g/GJ]**	**NMVOC 4) [g/GJ]**	**CH_4 5) [g/GJ]**	**CO 6) [g/GJ]**	**CO_2 [kg/GJ]**	**N_2O 7) [g/GJ]**
s	**sewage sludge**	**118**	**1,300 1)**	**2,000 1)**	**8 1)**	**150 1)**	**300 1)**	**820 1)**	**60 1)**
-	**not specified**	**-**	**100 - 4,000 1)**	**30 - 5,500 1)**	**20 - 450 1)**	**30 - 665 1)**	**400 - 360.000 1)**	**660 1)**	**30 - 400 1)**

1) CORINAIR90 data, area sources (preliminary data)

2)	**SO_x (EPA 1995)**	**14**	**kg/Mg**	**Uncontrolled**
		2.8	**kg/Mg**	**Cyclone, controlled**
		0.32	**kg/Mg**	**Impingement, controlled**
		2.3	**kg/Mg**	**Venturi, controlled**
		0.1	**kg/Mg**	**Venturi / impingement, controlled**
3)	**NO_x(EPA 1995)**	**2.5**	**kg/Mg**	**Uncontrolled**
4)	**NMVOC**	**0.84**	**kg/Mg**	**Uncontrolled**
	(EPA 1995)	**1.5**	**kg/Mg**	**Cyclone, controlled**
		0.22	**kg/Mg**	**Cyclone / venturi, controlled**
		0.78	**kg/Mg**	**Impingement, controlled**
5)	**CH_4**	**0.39**	**kg/Mg**	**Impingement**
	(EPA 1995)	**3.2**	**kg/Mg**	**Venturi**
6)	**CO (EPA 1995)**	**15.5**	**kg/Mg**	**Uncontrolled**
7)	**N_2O**	**227**	**g/t waste**	**rotary grate (combustion temperature 750 °C)**
	(De Soete 1993)	**580 - 1,528**	**g/t waste**	**Fluidised bed combustion (combustion temperature 770 - 812 °C)**
		684 - 1,508	**g/t waste**	**Fluidised bed combustion (combustion temperature 838 - 854 °C)**
		275 - 886	**g/t waste**	**Fluidised bed combustion (combustion temperature 834 - 844 °C)**
		101 - 307	**g/t waste**	**Fluidised bed combustion (combustion temperature 853 - 887 °C)**

In addition, emission factors for HCl, some heavy metals, and dioxins have been derived (Table 3). The range represents emission factors from modern advanced sewage sludge incinerators through to plant with only particle emission abatement equipment.

Table 3 Typical Emission Factors for Plant with only particle emission abatement equipment

Pollutant	Emission Factor g/te waste burnt	Quality Code	Reference
HCl	10 - 450	E	Leonard 1992 Mitchell 1992
Pb	0.001 - 1.8	E	Leonard 1992 Mitchell 1992
Cu	0.004 - 0.5	E	Leonard 1992 Mitchell 1992
Cd	0.9 - 1.3	E	Leonard 1992 Mitchell 1992
Cr	0.001 - 0.07	E	Leonard 1992 Mitchell 1992
Ni	0.001 - 0.07	E	Leonard 1992 Mitchell 1992
Hg	0.4 - 0.6	E	Leonard 1992 Mitchell 1992
Dioxins ug I-TEQ/te	5 - 120	E	Vereniging Lucht 1991

9 SPECIES PROFILES

The dioxin profile for the individual isomers measured to make up the Toxic Equivalence quoted above (Table 3) does not vary in overall shape between most combustion samples. The octa chlorinated dioxins and furans dominate the profile.

10 UNCERTAINTY ESTIMATES

The emission factors given for dioxins are taken from measurements at only two incinerators. Individual measurements demonstrate that the variability in dioxin concentration, at a single plant, can be an order of magnitude between different sampling periods. There were also wide differences noticeable in the emission factors available for other pollutants depending on which of the many combinations of gas cleaning equipment was in use on the plant. Hence any emission factor is subject to an uncertainty considerably greater than 100%.

The emission factors for pollutants in Table 2 are based on CORINAIR90 data and the wide range in results indicates the significant variability between sources and the uncertainty in the derivation of emission factors.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The emission factors provided in Table 2 are related to point sources and area sources without specification. CORINAIR90 data can only be used in order to give a range of emission factors with respect to point and area sources. The emission factors are unlikely to be typical of all European sewage sludge incinerators. Further work is required to develop emission factors, including technical or fuel dependent explanations concerning emission factor ranges.

No information is available on the fugitive emissions of heavy metals and dioxins associated with residue handling and disposal. This may represent a significant proportion of the total emission especially where advanced abatement equipment is fitted to an older plant.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

All sources should be considered point sources if possible. Otherwise disaggregation should be done on the basis of population or number of plants per territorial unit.

13 TEMPORAL DISAGGREGATION CRITERIA

The large incinerators operate as continuously as possible and should be treated as 24 hour 7 days a week emitters. The smaller plant less than 5 tonne per hour should be treated as 8 hour 5 days a week processes unless information available suggests otherwise.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

Verification is through comparison with emission estimates from other countries together with a measurement programme for selected sites except for trace organics as residual historical soil levels may greatly influence present day air concentrations.

17 REFERENCES

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19 RELEASE VERSION, DATE AND SOURCE

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List of abbreviations

FBC	fluidized-bed combustion
MSW	municipal solid waste
MHF	multiple hearth furnace
POM	persistent organic matter

SNAP CODE : 090206

SOURCE ACTIVITY TITLE : Flaring in Gas and Oil Extraction

1 ACTIVITIES INCLUDED

Flaring is gas combusted without utilisation of the energy. SNAP 090206 include all flaring for extraction and first treatment of gaseous and liquid fossil fuels. Flaring in oil refineries and other industry is described in SNAP 090203 and 090204, respectively. Emissions to air from incineration after a well testing should be reported in snap 090206 as well.

This section also includes flaring in gas terminals.

2 CONTRIBUTION TO TOTAL EMISSIONS

This source is significant for countries which produce oil and gas. For example:

	CO_2	NO_x	NMVOC	CH_4
Norway :[1]	2.3	1.7	0.0	0.0
UK:[2]	1.0	1.0	0.7	0.4
Average CORINAIR 1990:				

1 Statistics Norway and the State Pollution Control Authority
2 Passant 1993. UK National Atmospheric Emission Inventory

3 GENERAL

3.1 Description

Gas is flared on oil and gas production installations for safety. The main reasons are lack of process or transport capacity for gas, a continuous surplus gas flow, start up, maintenance and emergency (need for pressure relief). The gas is led through a pipeline to a flare tip located high above and away from the platform.

Well testing is performed as a part of the exploration activity. After a discovery the well is tested to check the production capacity and the composition of the reservoir fluid. Due to lack of treatment, storage and transport facilities the oil or gas extracted may be disposed by burning.

3.2 Definitions

Blanket gas:	Gas used to maintain a positive pressure in an atmospheric tank in order to avoid air ingress.
Glycol regeneration:	A process that reduces the water content in glycol by heating and gas stripping.

Pilot flame:	Flame that burns continuously in connection with a flare tip. The pilot burner is independent of the flare system. It is used to ensure re-ignition even if the main burner is extinguished.

3.3 Techniques

The combustion in the flare will depend on the gas composition, gas velocity (efficiency of the flare) and wind conditions. There are several types of flare burners which also may give different emissions. The design of the flare is determined primarily by the safety considerations.

3.4 Emissions/Controls

The emissions of pollutants from flaring are either unburned fuel or by-products of the combustion process. Different burner design may influence the characteristic of the emissions. Increased efficiency of combustion may reduce the CH_4 and NMVOC emissions. However, this might not reduce the NO_x emissions and will not reduce the CO_2 emissions. Major emissions from flaring are best reduced by reducing the amount of flared gas, without increasing the amount of gas directly vented.

Currently all flaring cannot be eliminated, but there is potential for substantially reducing the amount flared and technologies are now tested to reduce flaring further. Possibilities are:

High integrity pressure protection systems (HIPS): gas leakages are collected and brought back to the process system. The flare is only ignited when really necessary.

Use of nitrogen as a purge gas (to avoid explosions (blanking) and deoxygenation of water (stripping)).

Alternative methods for glycol regeneration

Re-injection of gas into gas reservoirs

Increased possibilities for transport and storage capacity of gas

Reduced requirements for a pilot flame.

4 SIMPLER METHODOLOGY

Emissions may be estimated from general emission factors applied to the volume of gas flared.

5 DETAILED METHODOLOGY

Field studies in collaboration with the industry to evaluate an emission factor for each flare. It is currently difficult to measure the actual emission from a flare. However, a better accuracy of the emission estimate may be achieved by judging the sort of flare, the intensity of the flare and the actual amount flared for each installation.

6 RELEVANT ACTIVITY STATISTICS

The volume of gas flared is the most relevant activity statistics. The volume of flare gas may be measured instrumentally or calculated. In Norway about 70 % of the platforms have metering systems, but this fraction is probably lower in most other countries. The uncertainty may be as high as 5-30 percent even if the gas is metered. A mass balance approach may be equally accurate.

Of ten Norwegian platforms the percentage of the gas production flared varied from 0.04 to 15.9. The volume of gas flared is usually higher on an oil production platform than on a gas production platform, since it is preferred to sell the gas rather than to flare it if there is a choice. Generally, the volume flared is higher on new platforms than on the old because the elder have had time to develop better procedures, have fewer shut downs and practice more direct venting of the gas. These figures show that most countries/platforms have a substantial potential for reducing flaring. The large range given of percentage of gas flared, shows the need for making inquiries to find the actual value. If this is not feasible, the higher value should be used.

For well testing the amount of oil and gas incinerated will be the activity statistics. However, it is unlikely that these data are readily available.

7 POINT SOURCE CRITERIA

The location of oil and gas production facilities are associated with specific oil and gas fields, where practical these fields should be considered as point sources.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Simpler Methodology

There have been relatively few measurements of emissions from flares. In the OLF study laboratory scale measurements were performed (OLF 1993). The emissions measured were extrapolated to the emissions from a real flare.

The CO_2 emission factor may be calculated from the average gas composition. If the average gas composition is not known, then the suggested default emission factor is 2300 g/Sm^3 gas (IPCC default emission factor for natural gas, IPCC 1994).

Emission factors for flaring:

Unit: g/Sm^3 gas

Country	SO_2	CO_2	NO_x	CO	NMVOC	CH_4	N_2O	Quality code
Norway[1]	0.0	2430	12	1	0.1	0.2	0.02	C
UK[2]	0.1	2360	10	10	10	10	0.004	D
Neth'ds[3]	-	-	-	-	14	2	-	D

[1] OLF 1993
[3] Brown and Root 1993. UK Digest of Energy statistics
[2] TNO

The OLF emission factors are recommended because they are based on documented measurements. However, more measurements of emissions from flares are needed to establish a more accurate set of emission factors. The reason for the low NMVOC and methane emission factors in the Norwegian study is that measurements have shown that unburned hydrocarbons are combusted while leaving the flare.

It may generally be assumed that fields with a high level of flaring have a more efficient flare.

Emission factors for well testing:

Unit: g/kg oil burned

Country	CO_2	NO_x	CO	VOC[2]	Quality code:
Norway[1]	3200	3.7	18	3.3	C

1 OLF 1993 2 Mainly methane

If gas is incinerated in the well testing, the general emission factors for flaring are recommended.

8.2 Detailed Methodology

The CO_2 emissions should be calculated from the average gas composition of each field. The gas composition may vary significantly from field to field.

For NO_x, the flare may be classified according to its flow rate. The lower the flow rate the lower the NO_x emission factor. The following equation may be used if better data are not available.

$$g\ NOx/Sm^3 = X + 20 \qquad \text{Equation 1}$$

Where X is the gas flow rate in terms of million m^3/day (Celius 1992).

For NMVOC, CH_4 and CO the emissions will be dependent on the load, and subsequent the efficiency of the flare, although no data are available. It may be assumed that the emissions of these compounds run against the NO_x trend.

9 SPECIES PROFILES

For the NMVOC no data are available.

10 UNCERTAINTY ESTIMATES

The CO_2 emission factor for the simplified methodology is within an accuracy of 10 percent. Emission factors for the other pollutants will vary considerably depending on the gas composition, loading and flare type. As a consequence use of the simplified methodology may result in an uncertainty much greater than 100 percent, depending on the pollutant. Celius 1992 has quoted an uncertainty of 50 % for the NO_x emission factor and a higher uncertainty for the other pollutants.

The uncertainty in the volume of gas flared is 5-30 % if measured, and about 30 % if calculated.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The suggested emission factors are based on few measurements. More representative measurements and full scale flare measurements are required to relate the emissions of the various pollutants with the flare conditions, i.e. the gas loading, gas composition and flare type.

Better accuracy on the volume of gas flared may be achieved through the use of more accurate measuring techniques and more measurement as opposed to calculation of gas flows.
Each field should report the following:

- The volume of gas flared
- The composition of the gas
- The type of flare used

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

All fields, off-shore and on-shore, may be defined geographically to a precise location. Where possible, therefore, quote emissions per field.

13 TEMPORAL DISAGGREGATION CRITERIA

Flaring does not depend on diurnal or seasonal factors. However, the volume of gas flared will change over the lifetime of the field. Monthly flaring data if available will be most accurate. Monthly production data are available in major oil and gas exporting countries. If this information is not available, emissions may be assumed equally temporally distributed. Equal temporal distribution night/day may generally be assumed.

14 ADDITIONAL COMMENTS

There are a number of developments in emission estimation methodologies in this area e.g. IPCC, OLF and UK OOA. This draft will have to be revised in the coming years in light of this.

15 SUPPLEMENTARY DOCUMENTS

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16 VERIFICATION PROCEDURES

Compare metered and calculated flaring volumes.

17 REFERENCES

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19 RELEASE VERSION, DATE AND SOURCE

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SNAP CODE: **090207**

SOURCE ACTIVITY TITLE **Incineration of Hospital Wastes**

NOSE CODE: **109.01.07**

1 ACTIVITIES INCLUDED

This section includes the volume reduction, by combustion, of hospital wastes. Principally this section covers the emissions from chimneys and ductwork because of the availability of measurement data.

In some cases hospital waste is combusted in municipal waste incinerators, or in ‘hazardous waste incinerators’ along with hazardous/ chemical wastes from industrial processes. Users of this chapter should be aware of the potential for double counting of activity data with this chapter and the chapters on SNAP 090201 and SNAP 090202.

2 CONTRIBUTION TO TOTAL EMISSIONS

The relative proportion of emissions contributed by hospital waste incineration varies between pollutants. The process is likely to be a source (0.1-1% of total European emissions) of some persistent organic pollutants (POPs), such as PCDD/Fs, HCBs, TRI, PER, TCE, PAHs and some heavy metals such as cadmium, mercury etc. (ETC/AEM-CITEPA-RISOE 1997).

Emissions of compounds such as volatile organic compounds (VOCs), sulphur dioxide and nitrogen oxides (NO_x, N_2O) from hospital waste incineration are unlikely to contribute significantly to total emissions (< 0.1%), while substances such as sulphurhexafluoride (SF_6), hydrofluorocarbons (HFCs) or perfluorocarbons (PFCs) are generally not relevant (ETC/AEM-CITEPA-RISOE 1997).

3 GENERAL

3.1 Description

Hospital waste may be identified as ‘specific hospital waste’ and ‘other hospital waste’. Specific hospital waste includes human anatomic remains and organ parts, waste contaminated with bacteria, viruses and fungi, and larger quantities of blood.

Incineration of hospital wastes has been banned in some European countries. In countries where the process is allowed, for the most part incinerators are currently small facilities located on-site at hospitals. However, there is generally a move towards larger, centralised facilities.

3.2 Definitions

BAT - best available technology.

HCB - hexachlorobenzene.

HWID - hazardous waste incineration directive.

I-TEQ - International Toxic Equivalent (of PCDD/Fs).

NMVOCs - non-methane volatile organic compounds.

PAHs - polycyclic aromatic hydrocarbons.

PCBs - polychlorinated biphenyls.

PCDD/Fs - polychlorinated dibenzo-para-dioxins and polychlorinated dibenzo furans - a series of chlorinated aromatic compounds, commonly known as 'dioxins'.

PER - tetrachloroethylene.

POPs - persistent organic pollutants.

TCE - trichloroethane.

TRI - trichloroethylene.

Adsorption using activated carbon / activated lignite coke - several different technologies have been developed for dioxin and mercury control. These systems can also be fairly effective at removing HCl and SO_2 and act as a useful polisher for these acid gases.

Controlled air incinerators - also known as modular starved air incinerators, are commonly used units, which consist of two stages. During the first stage (starved air section), the air-to-fuel ratio is kept low to promote drying and volatilisation at temperatures of ~ 800 - 900 °C. In the second stage (secondary combustion chamber) excess air is added and temperatures elevated to > 1000 °C by support burners to ensure complete gas phase combustion. The relatively low bed temperature and combustion air velocities mean that metal species tend to remain in the bed and, together with particulates, are less likely to be entrained in the flue gases than with other types of incinerator (e.g. excess air incinerators).

Dry sorbent injection systems - involve the injection of an alkaline reagent (e.g. calcium hydroxide or sodium bicarbonate) as a fine, dry powder to remove and neutralise acid gases. The neutralised product is normally collected in a fabric filter.

Electrostatic precipitators (ESP) - use the principle of electrostatic attraction to remove entrained particles from the flue gases. They consist of rows of discharge electrodes (wires or thin metal rods), through which a high voltage is applied, and which run between an array of parallel rows of metal plates which collect the charged particles (note - not very common in clinical waste incinerators).

Energy recovery - the removal of heat from the exhaust gases so as to provide heat and/or electricity for use in the plant or elsewhere.

Excess air incinerators - also referred to as batch incinerators, are typically small modular units consisting of a series of internal chambers and baffles. They are usually operated batchwise, but can be operated continuously. Excess air incinerators generally consist of two main chambers; a primary combustion chamber where drying and volatilisation occurs and a secondary chamber to ensure complete gas phase combustion. These plant are operated at lower temperatures than controlled air incinerators (secondary chamber temperature ~ 900 ° C), with complete combustion promoted by maintaining excess air levels of up to 300 % throughout (usually ~ 100 % for burning pathological waste only).

Fabric filters - consist of semi-permeable material in the form of bags or sleeves, which trap particles and which, are mounted in an airtight housing (baghouse) which is divided into a number of compartments. Fabric filters are also used as a second stage in acid gas control systems.

Rotary kiln - waste is fed into a slightly inclined, rotating, refractory-lined drum which acts as a grate surface. The rotating action of the drum mixes it with air supplied through the walls.

Semi-dry scrubbers / spray absorber systems (spray drying) - make use of an alkaline reagent slurry (usually calcium hydroxide) which is introduced into the flue gases as a spray of fine droplets. The acid gases are absorbed into the aqueous phase on the surface of these droplets and neutralised to form a dry product, which is collected in an electrostatic precipitator or fabric filter. Spray absorbers tend to use a reaction tower; of the several different designs available, the gas suspension absorber is the most commonly employed in hospital waste incinerators. This involves a re-circulation of particulate matter and unreacted lime back into the reaction tower.

Wet scrubbers - remove acid gases (e.g. HCl, HF and SO_2) by washing the flue gases in a reaction tower. Designed to provide a high gas-liquid contact. In the first stage, the gases are quenched by water sprays to remove HCl, HF, some particulates and some heavy metals. In the second stage, calcium hydroxide or another suitable alkali is used to remove SO_2 and any remaining HCl.

3.3 Techniques

There are many different furnace designs and combustion techniques used in Europe for hospital waste incineration. Generally, incinerators consist of the following components:

- a lidded charge box or feed hopper where the batch is first deposited;
- a hydraulic ram/ feeder which pushes the charge into the furnace;
- a pyrolysis furnace where the waste is degassed, releasing moisture and volatile components (at temperatures 800 - 900 °C);

- an after-burning chamber or secondary combustion chamber where the volatile components and products of incomplete combustion are completely destroyed by thermal oxidation in the presence of excess air, at temperatures above 1000 °C and with a gas residence time of 2 seconds;
- burners to heat up the plant when started, initiate combustion and to regulate the temperature in all parts, especially the secondary combustion chamber;
- a residue handling system.

Incinerator Size

Small incinerators (< 1 tonne/hr) may be designed to be operated during the day only, and tend to be used to incinerate batches. At start-up, the furnace is heated using support burners and, if required, the burning of domestic hospital waste. Daily, after the last waste input, the furnaces are maintained at temperature for a further 2 - 4 hours using the burners. The furnace is then cooled by leading ambient air through it for a number of hours before manual de-ashing is carried out.

Larger incinerators (> 1 tonne/hr) normally employ continuous operation. Conditions are adapted to ensure that there is effective combustion throughout, e.g. by using multi-hearth plant or rotary kilns under appropriate conditions of temperature/ air.

The main influences on the total emission expected from these incinerators are the waste burning capacity of the incinerator, the type of plant, the way in which it is operated (e.g. whether it includes heat recovery), its gas phase combustion efficiency and the degree of abatement fitted to the plant.

3.4 Emissions

The most significant pollutants from this process are some heavy metals (e.g. Pb, Cu, Cd, Cr, Ni, Hg). A variety of organic compounds, including PCDD/Fs, chlorobenzenes, chloroethylenes and polycyclic aromatic hydrocarbons (PAHs), are present in hospital waste or can be formed during the combustion and post-combination processes. Organics in the flue gas can exist in the vapour phase or can be condensed or absorbed on fine particulates.

Other pollutants released are HCl, sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOCs and methane (CH_4)), carbon monoxide (CO), carbon dioxide (CO_2) and nitrous oxide (N_2O).

Carbon monoxide emissions result when carbon in the waste is not completely oxidised to carbon dioxide (CO_2). High levels of CO normally indicate that the combustion gases were not held at a sufficiently high temperature in the presence of oxygen (O_2) for a long enough time to convert CO to CO_2, or that quenching has occurred. Because O_2 levels and air distributions vary among combustor types, CO levels also vary among combustor types. Carbon monoxide concentration is a good indicator of gas phase combustion efficiency, and is an important criterion for indicating instabilities and non-uniformities in the combustion process (US EPA 1995).

Nitrogen oxides are products of all fuel/air combustion processes. Nitric oxide (NO) is the primary component of NO_x; however, nitrogen dioxide (NO_2) and nitrous oxide (N_2O) are also formed in smaller amounts. Nitrogen oxides are formed during combustion through oxidation of nitrogen in the waste, and oxidation of atmospheric nitrogen. Conversion of nitrogen in the waste occurs at relatively low temperatures (less than 1,090 °C), while oxidation of atmospheric nitrogen occurs at higher temperatures. NO_x from hospital waste incineration is typically lower than from other waste incineration processes.

3.5 Controls

Emissions may be controlled by modification of process techniques and physical parameters to optimise combustion conditions, or by employment of abatement techniques. The level of abatement at an incinerator plant varies, depending on the size of the plant, age and emission regulations etc.

Generally, there are three types of plant (LUA, 1997):

- type 1 are small on-site plants without abatement technology;
- type 2 are larger on-site facilities equipped with de-dusting systems;
- type 3 are incinerators which comply with the hazardous waste directive.

There are also a large number of facilities, which are intermediate between types 2 and 3, with varying levels of abatement.

Mainly for economic reasons, in recent years there has been a move towards larger, modern plant. Such plant includes emission abatement equipment, which aim to ensure compliance with emission regulations, addressing the three main environmental impacts of waste incineration/ products of incomplete combustion: acid gas, heavy metal and dioxin emissions. Typical approaches used include:

- good combustion practice - optimal conditions of time/ temperature/ turbulence/ air to ensure complete oxidation of products of incomplete combustion;
- wet scrubbers (acid gas removal);
- fabric filters (particle control);
- electrostatic precipitators (particle control);
- semi-dry scrubbers / spray absorber systems (acid gas removal);
- dry sorbent injection systems (acid gas removal);
- adsorption using activated carbon / activated lignite coke (PCDD/F and mercury removal).

These control systems are described in section 3.2. These systems are usually needed in combination.

4 SIMPLER METHODOLOGY

The simpler methodology relies on the use of a single emission factor for each pollutant species combined with a national hospital waste incineration statistic:

Total emission = mass of hospital waste incinerated (tonnes) x overall emission factor (emission per tonne of waste incinerated) (1)

A typical emission factor for hospital waste incinerators within a country can be estimated from the emission factors given in section 8 combined with knowledge of the typical level of abatement and its efficiency:

Typical overall emission factor = baseline emission factor (uncontrolled) x (1 - overall abatement efficiency) (2)

5 DETAILED METHODOLOGY

The detailed methodology involves the use of plant specific emission factors calculated from regulatory emission measurement programmes and using plant specific throughput data normally obtained by each plant. The detailed method will therefore involve the use of a similar equation to the one in section 4, but the equation will be plant specific.

6 RELEVANT ACTIVITY STATISTICS

6.1 Simpler methodology

For the simpler methodology the national annual incineration of hospital waste is required. In addition, a more reliable estimate can be made if information is available on the typical levels of abatement technology used and on the associated overall abatement efficiency.

In determining the emissions from the incineration of hospital waste, one of the most difficult tasks for the user is to correctly derive the fraction of waste actually being incinerated from the overall clinical waste being produced in a country.

6.2 Detailed methodology

The more detailed method requires information on plant specific waste throughput and abatement technology, obtained from the operators.

If neither of these values is available the mass burn rate of each incinerator should be multiplied by an estimated operating time.

7 POINT SOURCE CRITERIA

The number of clinical waste incinerators is small so they may be treated as point sources if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Simpler Methodology

Tables 8.1 to 8.20 give default emission factors for the most significant pollutants, where available, for:

- type 1 plant - small on-site facilities without abatement technology;
- type 2 plant - larger on-site facilities equipped with de-dusting systems;
- type 3 plant - facilities, which comply with the hazardous waste incineration directive (HWID) (94/67/EC).

Data for specific plant configurations (controlled air/ rotary kiln) are also included where available for a variety of abatement options. [* denotes limited data available].

No emission factors are available for HCB, TRI, PER, TCE or PAHs.

Users of the Guidebook are advised to consider that from country to country the composition of the incinerated waste may vary due to differences in waste definitions and fractionation. This could lead to country-specific emission factors that are not comparable to those of other countries.

Table 8.1 – Default Emission Factors for Aluminium (Al)

Compound	**Plant type**	**Emission factor** g/tonne waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
Al	Controlled air	5	E	uncontrolled	USA	US EPA 1998
Al	Controlled air	2*	E	controlled (various types of abatement)	USA	US EPA 1998
Al	Rotary kiln	306	E	uncontrolled	USA	US EPA 1998
Al	Rotary kiln	1 - 2	E	controlled (various types of abatement)	USA	US EPA 1998

Table 8.2 – Default Emission Factors for Antimony (Sb)

Compound	**Plant type**	**Emission factor** g/tonne waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
Sb	Controlled air	6	D	uncontrolled	USA	US EPA 1998
Sb	Controlled air	0.1 - 0.2	E	controlled (various types of abatement)	USA	US EPA 1998
Sb	Rotary kiln	10	E	uncontrolled	USA	US EPA 1998
Sb	Rotary kiln	0.1 - 0.2	E	controlled (various types of abatement)	USA	US EPA 1998

Table 8.3 – Default Emission Factors for Arsenic (As)

Compound	**Plant type**	**Emission factor** g/tonne waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
As	Controlled air	0.1	B	uncontrolled	USA	US EPA 1998
As	Controlled air	0.00002 - 0.07	E	controlled (various types of abatement)	USA	US EPA 1998
As	Rotary kiln	0.2	E	uncontrolled	USA	US EPA 1998

Table 8.4 – Default Emission Factors for Barium (Ba)

Compound	**Plant type**	**Emission factor** g/tonne waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
Ba	Controlled air	2	B	uncontrolled	USA	US EPA 1998
Ba	Controlled air	0.04 - 0.1	E	controlled (various types of abatement)	USA	US EPA 1998
Ba	Rotary kiln	45	E	uncontrolled	USA	US EPA 1998
Ba	Rotary kiln	0.06 - 0.1	E	controlled (various types of abatement)	USA	US EPA 1998

Table 8.5 – Default Emission Factors for Beryllium (Be)

Compound	**Plant type**	**Emission factor** g/tonne waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
Be	Controlled air	0.003	D	uncontrolled	USA	US EPA 1998
Be	Controlled air	0.002*	E	controlled (various types of abatement)	USA	US EPA 1998
Be	Rotary kiln	0.02	E	uncontrolled	USA	US EPA 1998
Be	Rotary kiln	0.003*	E	controlled (various types of abatement)	USA	US EPA 1998

Table 8.6 – Default Emission Factors for Cadmium (Cd)

Compound	**Plant type**	**Emission factor** g/tonne waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
Cd	type 1	7 – 17	D/ C	none	UK	Wenborn et al. 1998
Cd	type 2	6 – 9	C	particle abatement only (dedusting)	UK	Wenborn et al. 1998
Cd	type 3	1	D	BAT for compliance with HWID	UK	Wenborn et al. 1998
Cd	Controlled air	3	B	uncontrolled	USA	US EPA 1998
Cd	Controlled air	0.006 – 3	E	controlled (various types of abatement)	USA	US EPA 1998
Cd	Rotary kiln	8	E	Uncontrolled	USA	US EPA 1998
Cd	Rotary kiln	0.01 - 0.03	E	Controlled (various types of abatement)	USA	US EPA 1998

Table 8.7 – Default Emission Factors for Chromium (Cr)

Compound	**Plant type**	**Emission factor** g/tonne waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
Cr	Controlled air	0.4	B	Uncontrolled	USA	US EPA 1998
Cr	Controlled air	0.001 - 0.5	E	Controlled (various types of abatement)	USA	US EPA 1998
Cr	Rotary kiln	2	E	Uncontrolled	USA	US EPA 1998
Cr	Rotary kiln	0.04 - 0.05	E	Controlled (various types of abatement)	USA	US EPA 1998

Table 8.8 – Default Emission Factors for Copper (Cu)

Compound	**Plant type**	**Emission factor** g/tonne waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
Cu	Controlled air	0.6	E	uncontrolled	USA	US EPA 1998
Cu	Controlled air	0.1 - 0.6	E	controlled (various types of abatement)	USA	US EPA 1998
Cu	Rotary kiln	98	E	uncontrolled	USA	US EPA 1998
Cu	Rotary kiln	0.2 - 0.3	E	controlled (various types of abatement)	USA	US EPA 1998

Table 8.9 – Default Emission Factors for Iron (Fe)

Compound	**Plant type**	**Emission factor** g/tonne waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
Fe	Controlled air	0.7	C	uncontrolled	USA	US EPA 1998
Fe	Controlled air	0.5*	E	controlled (various types of abatement)	USA	US EPA 1998

Table 8.10 – Default Emission Factors for Lead (Pb)

Substance	**Plant type**	**Emission factor** g/tonne of waste	**Data Quality**	**Abatement type**	**Country**	**Reference**
Pb	type 1	75 - 150	D/ C	none	UK	Wenborn et al. 1998
Pb	type 2	54 - 74	C	particle abatement only (dedusting)	UK	Wenborn et al. 1998
Pb	type 3	5	D/ C	BAT for compliance with HWID	UK	Wenborn et al. 1998
Pb	Controlled air	364	B	uncontrolled	USA	US EPA 1998
Pb	Controlled air	0.03 - 40	E	controlled (various types of abatement)	USA	US EPA 1998
Pb	Rotary kiln	62	E	uncontrolled	USA	US EPA 1998
Pb	Rotary kiln	0.04 - 0.1	E	controlled (various types of abatement)	USA	US EPA 1998

Table 8.11 – Default Emission Factors for Manganese (Mn)

Compound	**Plant type**	**Emission factor** g/tonne waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
Mn	Controlled air	0.3	C	uncontrolled	USA	US EPA 1998
Mn	Controlled air	0.2 - 0.3	E	controlled (various types of abatement)	USA	US EPA 1998

Table 8.12 – Default Emission Factors for Mercury (Hg)

Compound	**Plant type**	**Emission factor** g/tonne waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
Hg	type 1	not available	N/A	none	UK	Wenborn et al. 1998
Hg	type 2	4 –5	C	particle abatement only (dedusting)	UK	Wenborn et al. 1998
Hg	type 3	1	C/ D	BAT for compliance with HWID	UK	Wenborn et al. 1998
Hg	Controlled air	54	C	uncontrolled	USA	US EPA 1998
Hg	Controlled air	0.2 – 15	E	controlled (various types of abatement)	USA	US EPA 1998
Hg	Rotary kiln	43	E	Uncontrolled	USA	US EPA 1998
Hg	Rotary kiln	4 – 33	E	Controlled (various types of abatement)	USA	US EPA 1998

Table 8.13 – Default Emission Factors for Nickel (Ni)

Compound	**Plant type**	**Emission factor** g/tonne waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
Ni	Controlled air	0.3	B	uncontrolled	USA	US EPA 1998
Ni	Controlled air	0.1 – 16	E	controlled (various types of abatement)	USA	US EPA 1998
Ni	Rotary kiln	2	E	uncontrolled	USA	US EPA 1998
Ni	Rotary kiln	0.02 - 0.04	E	controlled (various types of abatement)	USA	US EPA 1998

Table 8.14 – Default Emission Factors for PCDD/Fs

Compound	**Plant type**	**Emission factor** µg I-TEQ/tonne of waste	**Data Quality**	**Abatement type**	**Country**	**Reference**
PCDD/Fs	type 1	800 – 2500	E	none	W Europe	LUA 1997, Berdowski 1995
PCDD/Fs	type 2	80 – 250	D/E	particle abatement only (dedusting)	W Europe	LUA 1997, Berdowski 1995
PCDD/Fs	type 3	1	D/C	BAT for compliance with HWID	W Europe	LUA 1997, Berdowski 1995

Table 8.15 – Default Emission Factors for Polychlorinated Biphenyls (PCBs)

Compound	**Plant type**	**Emission factor** g/tonne of waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
PCBs (total)	Controlled air	0.02	E	uncontrolled	USA	US EPA 1998

Table 8.16 – Default Emission Factors for HCl

Compound	**Plant type**	**Emission factor** g/tonne of waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
HCl	Controlled air	16800	C	uncontrolled	USA	US EPA 1998
HCl	Controlled air	5- 6370	E	controlled (various types of abatement)	USA	US EPA 1998
HCl	Rotary kiln	22100	E	uncontrolled	USA	US EPA 1998
HCl	Rotary kiln	134 – 14700	E	controlled (various types of abatement)	USA	US EPA 1998

Table 8.17 – Default Emission Factors for Particulates (PM)

Compound	**Plant type**	**Emission factor** g/tonne of waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
PM	Controlled air	2330	B	uncontrolled	USA	US EPA 1998
PM	Controlled air	36-1450	E	controlled (various types of abatement)	USA	US EPA 1998
PM	Rotary kiln	17300	E	uncontrolled	USA	US EPA 1998
PM	Rotary kiln	39 – 427	E	controlled (various types of abatement)	USA	US EPA 1998

Table 8.18 – Default Emission Factors for Carbon Monoxide (CO)

Compound	**Plant type**	**Emission factor** g/tonne of waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
CO	Controlled air	1480	A	uncontrolled	USA	US EPA 1998
CO	Rotary kiln	191	E	uncontrolled	USA	US EPA 1998
CO	Rotary kiln	19 – 30	E	controlled (various types of abatement)	USA	US EPA 1998

Table 8.19 – Default Emission Factors for NO_x

Compound	**Plant type**	**Emission factor** g/tonne of waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
NO_x	Controlled air	1780	A	uncontrolled	USA	US EPA 1998
NO_x	Rotary kiln	2310	E	uncontrolled	USA	US EPA 1998
NO_x	Rotary kiln	2040 – 2630	E	controlled (various types of abatement)	USA	US EPA 1998

Table 8.20 – Default Emission Factors for SO_2

Compound	**Plant type**	**Emission factor** g/tonne of waste	**Data Quality**	**Abatement type**	**Country or region**	**Reference**
SO_2	Controlled air	1090	B	uncontrolled	USA	US EPA 1998
SO_2	Controlled air	8 – 1040	E	controlled (various types of abatement)	USA	US EPA 1998
SO_2	Rotary kiln	540	E	uncontrolled	USA	US EPA 1998
SO_2	Rotary kiln	150 – 324	E	controlled (various types of abatement)	USA	US EPA 1998

9 SPECIES PROFILES

The dioxin profile for the relative emissions of the individual isomers measured to make up the Toxic Equivalence does not vary in overall shape between most combustion samples. The profile is likely to be dominated by octa-chlorinated dioxins and furans.

10 UNCERTAINTY ESTIMATES

Emission factors are likely to vary considerably between different incinerators, depending on the operating conditions and on which of the many combinations of gas cleaning equipment is in use on the plant. The variability at just a single plant for PCDD/Fs, for example, can be an order of magnitude between different sampling periods. The ranges in emission factors and the data quality ratings (mainly C, D or E) demonstrate the high uncertainty.

11 WEAKEST ASPECTS / PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Further work should be invested to develop emission factors, both to reduce the uncertainty of the emission factors in section 8, and to include important pollutants for which no information is available (e.g. other POPs). Improvements to emission factors would be easier if the measurement information collected by national regulatory authorities was collated.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

All sources should be considered point source if possible.

13 TEMPORAL DISAGGREGATION CRITERIA

Unless information available suggests otherwise, the smaller plant operating at less than 1 tonne per hour should be treated as 8 hour 5 days a week processes. It is likely that larger incinerators may operate more continuously and should be treated as 24 hour 7 days a week processes.

14 ADDITIONAL COMMENTS

No additional comments

15 SUPPLEMENTARY DOCUMENTS

No supplementary documents are required.

16 VERIFICATION PROCEDURES

Verification is through comparison with emission estimates from different countries together with a measurement programme for selected sites.

17 REFERENCES

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19 RELEASE VERSION, DATE AND SOURCE

Version:	1.0
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SNAP CODE :	**090400** **090401** **090402** **090403**
SOURCE ACTIVITY TITLE :	**Solid Waste Disposal on Land** **Managed Waste Disposal on Land** **Unmanaged Waste Disposal on Land** **Other**

This is a new sub group created so that the activities previously covered in 091004 on Landfilling can be sub divided and 091004 removed.

The expert panel leaders for this activity are listed below.

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SNAP CODE : **090700**

SOURCE SUB-SECTOR TITLE : **Open Burning of Agricultural Wastes (Except Stubble Burning)**

1 ACTIVITIES INCLUDED

This chapter covers the volume reduction, by open burning, of agricultural wastes. It does not include stubble burning, which is covered under SNAP code 100300, or forest fires, which is covered under SNAP code 110300. The open burning of rubber tyres or waste oil on farms has also not been included.

Examples of agricultural wastes that might be burned are crop residues (e.g. cereal crops, peas, beans, soya, sugarbeet, oil seed rape etc.) wood, leaves, animal carcasses, plastics and other general wastes. Straw and wood are often used as the fuel for the open burning of agricultural wastes. Poultry and animal excreta are difficult to burn except under controlled conditions.

2 CONTRIBUTION TO TOTAL EMISSIONS

The open burning of agricultural waste is likely to be widespread, although it will rarely be a significant source of emissions except on a local scale for short time periods.

Table 1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**							
		SO_2	**NO_x**	**NMVOC**	**CH_4**	**CO**	**CO_2**	**N_2O**	**NH_3**
Open Burning of Agricultural Wastes	**090700**	**-**	**0.9**	**1.8**	**0.8**	**5.8**	**0.3**	**0.3**	**-**

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

3 GENERAL

3.1 Description

The emissions arising from open burning depend on a number of factors. The most important variables are the type of waste burned and the moisture content of the waste. The ambient temperature and wind conditions, and the density/compactness of the pile of waste also affect the combustion conditions and hence the emissions.

3.2 Definitions

3.3 Techniques

The open burning of agricultural waste is carried out on the ground, in pits in the ground, or in open drums or wire mesh containers/baskets.

3.4 Emissions/Controls

One of the main concerns regarding agricultural waste combustion is the emission of smoke/particulates (MAFF 1992). Toxic organic micropollutants, such as polycyclic aromatic hydrocarbons (PAHs) and dioxins are likely to be present in the emissions. In many cases the combustion will be slow and inefficient, and therefore emissions of carbon monoxide (CO) and volatile organic compounds (VOCs) will be more significant than emissions of oxides of nitrogen (NO_X). The burning of plastics is likely to produce particularly toxic emissions, such as dioxins, other chlorinated organic compounds and cyanides.

The application of abatement equipment to open burning is impractical. However, changes in certain agricultural practices can reduce emissions. Waste minimisation and recycling, and the use of other more environmentally acceptable disposal methods, such as composting, reduces the quantity of agricultural waste burned.

The recycling and reuse of plastics, or the use of disposal methods other than burning, is particularly important.

The disposal of animal carcasses by methods other than open burning, such as to a licensed incinerator or landfill site, is likely to cause significantly less pollution.

Methods to improve the oxygen supply to the agricultural waste during combustion, and the burning of dry waste only, will improve the combustion conditions and reduce the emissions.

4 SIMPLER METHODOLOGY

The simpler methodology involves the use of a single emission factor for each pollutant representing the emission per mass of waste burned. This requires a prior knowledge of the weight of agricultural waste produced per hectare of farmland. It is assumed that open burning of agricultural waste (except stubble burning) is mainly practised in arable farming; emissions from open burning for other types of farming are likely to be less significant and are assumed to be negligible.

The dry weight of crop residue arisings for an average hectare of cereal crops has been estimated to be 5 tonnes per hectare (Lee and Atkins 1994). Most of this crop residue is burned as stubble or ploughed into the ground. Using this figure as a guide, it is assumed that the average quantity of agricultural waste disposed of by open burning (except stubble burning) is equivalent to between 0.5% of dry crop residue arisings in UNECE countries. The actual figure for each country will vary depending on farming practices and other available methods of disposal. The average amount of waste burned for arable farmland is therefore estimated to be 25 kg/hectare.

5 DETAILED METHODOLOGY

An improvement of the simpler methodology can be achieved by estimating the weight of waste produced per hectare for different types of farming, and, in the case of arable farming, for different types of crop. This would require a more detailed review of farming practices.

6 RELEVANT ACTIVITY STATISTICS

For the simpler methodology the national area of arable farmland is required. If a more detailed methodology is required then the breakdown of the national area of farmland into different types of farming (including the breakdown of arable farming into areas of different crops) would be needed.

7 POINT SOURCE CRITERIA

This activity should be considered as an area source.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

There is no information available on emissions from the open burning of agricultural waste by methods other than stubble burning. It has been assumed that emission factors for the open burning of agricultural waste will be similar to stubble burning and forest fires, for which some research has been carried out. Emission factors have been derived for dioxins, PAHs, VOCs and ammonia.

Table2: Typical Emission Factors for Dioxins and PAHs

Pollutant	Emission Factor g/tonne waste burned	Quality Code	Reference
Dioxins	10 µg I-TEQ/tonne	D	Bremmer et al. 1994 Thomas and Spiro 1994
PAHs	100 g/tonne	D	Ramdahl 1983 Wild & Jones 1995
VOCs	2 kg/tonne	D	Passant 1993 Lee and Atkins 1994
NH_3 NH_4	1.9 kg/tonne 0.5 kg/tonne	D D	Lee and Atkins 1994

In addition Bailey et al. (1993) give a range of emission factors for aldehyde emissions from stubble burning as 0.03-0.47 kg/tonne (expressed as formaldehyde). Mariani et al. (1992) measured PAHs, PCBs and dioxins in the stack from an incinerator burning biomass (eg olive residues, wood chips), and also detected Cd, Pb, Hg, Cu in the incinerator ashes.

9 SPECIES PROFILES

The dioxin profile for individual isomers is only reported in a few of the relevant reports. It is dominated by the tetra and octa chlorinated dioxins and furans.

Similarly, emissions data is rarely reported for individual PAH compounds. Wild and Jones reported emissions of 6 PAHs from stubble burning; pyrene and benz(a)anthracene/chrysene were detected in the largest quantities.

VOC emissions from straw and stubble burning have not been characterised (Rudd 1995), and this is likely to be the same for other agricultural burning methods.

10 UNCERTAINTY ESTIMATES

There are little data on emissions from the open burning of agricultural waste (not including stubble burning). However, stubble burning is likely to involve similar combustion conditions to the open burning of agricultural waste, and therefore similar emission factors can be applied. As for many reports on emissions of PAHs and dioxins, significant uncertainty is caused by the fact that ‘total’ PAHs or ‘total’ dioxins in emissions from stubble burning are generally reported, whereas it is likely that only a limited number of compounds were measured.

Although information on the area of farmland is likely to be reliable, the estimation of the weight of waste arising per hectare of farmland is very uncertain.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

No reliable information is available on the quantity of agricultural waste that is disposed by open burning (not including stubble burning) and its estimation is the main area for improvement in the current methodology.

In addition, no data is available on emission factors for pollutants other than dioxins, PAHs VOCs and ammonia.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Spatial disaggregation requires the knowledge of the location of the farms that will carry out a significant amount of open burning of agricultural waste (other than stubble burning). These are likely to be arable farms as opposed to farms with mainly livestock. Spatial disaggregation might be possible if the detailed methodology were developed as this would involve the estimation of emissions from different types of farm.

13 TEMPORAL DISAGGREGATION CRITERIA

Temporal disaggregation requires the knowledge of current agricultural practices. It is likely that more burning will take place at the time of harvesting.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

A detailed study of agricultural burning practices should be carried out so that the methodology can be verified. In addition, a measurement programme for the emissions from the burning of the most common agricultural wastes is required.

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19 RELEASE VERSION, DATE AND SOURCE

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SNAP CODE: **090900**
090901

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

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

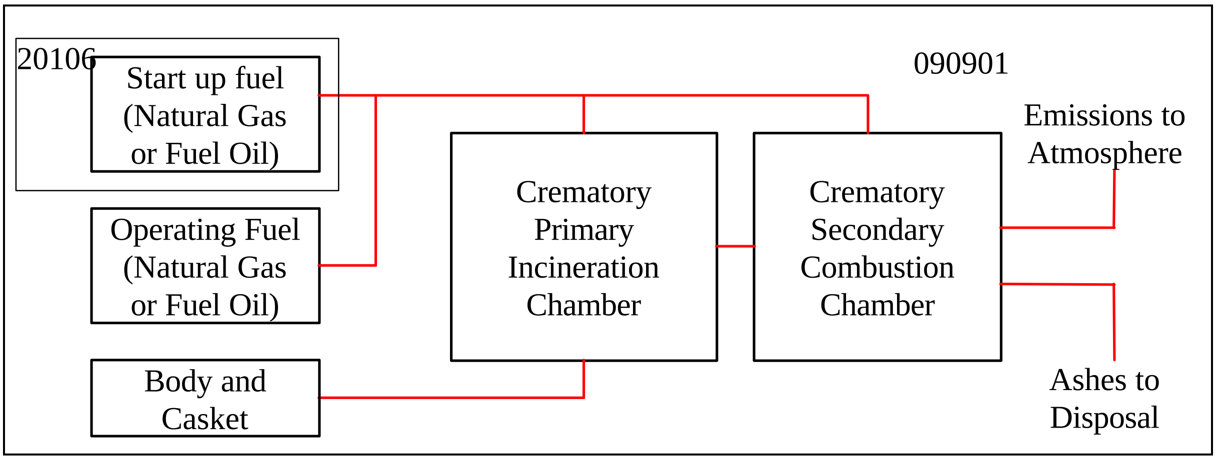
Country	SNAP code	Year	Contribution to total Emissions [%]							
			As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Canada(1)	090901	1990	0	0	0	0	.02	0	0	0
United States(2)	090901	1995			-		0			
Austria(3)	090901	1990	-	-	-	-	.03	-	-	-
Belarus(3)	090901	1990	-	-	-	-	1.1	-	-	-
Belgium(3)	090901	1990	-	-	-	-	.10	-	-	-
Germany(3)	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

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.

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.

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 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

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16 VERIFICATION PROCESS

Verification of emissions estimation can be done though stack measurements.

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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

Version : 1.0

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SNAP CODE : 090902

SOURCE ACTIVITY TITLE : Incineration of Carcasses

A specific methodology for these activities has not been prepared because the contribution to total national emissions is thought to be currently insignificant, i.e. less than 1% of national emissions of any pollutant.

If you have information contrary to this please contact the expert panel leaders.

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SNAP CODE : **091001**
091002

SOURCE ACTIVITY : **Waste Water Treatment in Industry**
Waste Water Treatment in Residential/Commercial Sectors

1 ACTIVITIES INCLUDED

The installations described are biological treatment plants. During the treatment process carbon dioxide, methane, and nitrous oxide can be produced. The emission factors given apply to a typical installation in the Netherlands in 1993.

This chapter was originally written for SNAP90 code 090100 Waste Water Treatment which covered the Industry and Residential/Commercial Sectors without differentiation.

2 CONTRIBUTION TO TOTAL EMISSION

The contribution of the emissions into air is minor, and only of local importance.

Table 1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	SNAP-code	Contribution to total emissions [%]							
		SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3
Waste Water Treatment	**090100 ***	**0**	**0**	**0.1**	**0.5**	**-**	**-**	**0.4**	**0.2**

* = SNAP90 code
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

3 GENERAL

3.1 Description of activities

3.2 Definitions

The main type of wastewater treatment plants in the Netherlands are low-load biological treatment plants with aeration by point aerators. For dephosphatizing the simultaneous process is mostly used. Denitrification generally occurs by creating anaerobic zones in the wastewater treatment basin.

4 SIMPLER METHODOLOGY

A calculation of the emissions from wastewater treatment plants should be based on a summation of emissions from individual plants. The emission factors given below should only be used as default values.

5 DETAILED METHODOLOGY

Emission calculations should be based on plant specific conditions.

6 RELEVANT ACTIVITY STATISTICS

In the Netherlands statistical material about individual wastewater treatment plants is gathered yearly by the Central Bureau of Statistics. The enquiry includes information about the load, the effluent and sludge quality, as well as economical aspects.

7 POINT SOURCE CRITERIA

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Table 2: Emission factors for emissions to air from wastewater treatment plants

Substance	Emission factor	
Emission to air	$kg.ie^{-1}$	$g\ m^{-3}$
carbondioxide	27.4	339.1
methane	0.3	3.7
dinitrogenoxide	0.02	0.25

i.e.: capita equivalent

The emission factors are based on mean values for the situation in the Netherlands in 1991. They can therefore not be applied to an individual plant, and give only a first approximation of the emissions. The accuracy classification is estimated to be D.

9 SPECIES PROFILES

10 UNCERTAINTY ESTIMATES

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENTS IN CURRENT METHODOLOGY

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

13 TEMPORAL DISAGGREGATION CRITERIA

Wastewater treatment is generally a continuous process.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

Emissions calculated should be compared with measurements at an individual plant.

17 REFERENCES

1 WESP document “RIOOLWATERZUIVERINGSINRICHTINGEN (RWZI’s) RIVM report 7730030003, RIZA report 93.046/M1 (in dutch)

2 C.Kroeze (1994). Nitrous oxide emission inventory and options for control in the Netherlands. RIVM report 773001004

18 BIBLIOGRAPHY

19 RELEASE VERSION, DATE AND SOURCE

Version: 0.1

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Source: J.J.M. Berdowski, P.F.J van der Most
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The Netherlands

SNAP CODE : 091003

SOURCE ACTIVITY TITLE : Sludge Spreading

1 ACTIVITIES INCLUDED

Emissions from the spreading of sewage sludge can be considered as a part of a wastewater treatment plant.

2 CONTRIBUTION TO TOTAL EMISSIONS

Table 1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code***	**Contribution to total emissions [%]**							
		SO_2	**NO_x**	**NMVOC**	**CH_4**	**CO**	**CO_2**	**N_2O**	**NH_3**
Sludge Spreading	**091003**	**-**	**-**	**0.1**	**0.3**	**-**	**-**	**-**	**0.1**

* = SNAP90 code 090300

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)

\- = no emissions are reported

3 GENERAL

3.1 Description

The sludge produced in a wastewater treatment plant is either burned, mechanically dried or dried by spreading in the open air. Information on emissions from the latter process is scarce. Emissions to air include odours. Recent measurements indicate that some ammonia is also produced. These emissions are considered in this chapter.

In the Netherlands some information on the composition of communal sludge is available. Some of the pollutants, especially halogenated hydrocarbons and PAHs might also become airborne on spreading.

4 SIMPLER METHODOLOGY

The simpler methodology would be to multiply the activity level by the ammonia emission factor to get the ammonia emission.

5 DETAILED METHODOLOGY

6 RELEVANT ACTIVITY STATISTICS

Standard statistics on sludge production and the fraction that is dried by spreading.

7 POINT SOURCE CRITERIA

This activity should be considered as an area source.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

The amount of ammonia produced by sludge spreading is determined by the dry matter content of the sludge and the total amount of ammoniacal nitrogen present. The dry matter content of a communal sludge may be between 4% (digested) and 5% (undigested).

Recent results from the United Kingdom gave a percentage ammonia of about 5% of the total ammonia-nitrogen content of the sludge.

9 SPECIES PROFILES

10 UNCERTAINTY ESTIMATES

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

13 TEMPORAL DISAGGREGATION CRITERIA

Emissions from sludge spreading can be regarded as continuous.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

NVA Slibcommissie 1994
Slibwijzer (in Dutch)

16 VERIFICATION PROCEDURES

17 REFERENCES

Webb, J., ADA Food, Farming, Land and Leisure, personal communication, 1995.

Sommer, S.G., Olesen, J.E., Journal of environmental quality Vol. 20 (1991), pp. 679-683 Waste management. Effect of dry matter content and temperature on ammonia loss from surface applied cattle slurry.

18 BIBLIOGRAPHY

19 RELEASE VERSION, DATE AND SOURCE

Version : 0.1

Date : November 1995

Source : P.F.J. van der Most
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The Netherlands

SNAP CODE : **091005**

SOURCE ACTIVITY TITLE : **Compost Production from Waste**

1 ACTIVITIES INCLUDED

This chapter covers compost production from organic waste.

2 CONTRIBUTION TO TOTAL EMISSIONS

Table 1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code***	**Contribution to total emissions [%]**							
		SO_2	**NO_x**	**NMVOC**	**CH_4**	**CO**	**CO_2**	**N_2O**	**NH_3**
Compost Production from Waste	**091005**	**-**	**-**	**-**	**0.1**	**-**	**0.6**	**-**	**-**

* = SNAP90 code 090500
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
\- = no emissions are reported

3 GENERAL

3.1 Description

In many areas organic domestic waste is gathered separately. Composting the organic waste produces a reusable product. The main emissions to be expected have to do with odour and abatement methods are directed at reducing the odour. Also a small amount of ammonia is produced.

4 SIMPLER METHODOLOGY

The simpler methodology would be to multiply the activity level by the ammonia emission factor to provide the ammonia emission.

5 DETAILED METHODOLOGY

6 RELEVANT ACTIVITY STATISTICS

Standard statistics on amounts of organic domestic waste produced.

7 POINT SOURCE CRITERIA

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

The amount of ammonia produced by composting domestic organic waste is estimated to be about 240 gram ammonia per ton organic waste. Using a biofilter with an efficiency of 90% reduces this amount to 24 gram per ton waste. The accuracy of this figure is estimated as D.

9 SPECIES PROFILES

10 UNCERTAINTY ESTIMATES

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

13 TEMPORAL DISAGGREGATION CRITERIA

Emissions from composting organic waste can be regarded as continuous.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

17 REFERENCES

Milieueffect rapport GECO 400 VAM NV. (1994)

C. Peek, RIVM, personal communication, 1995.

18 BIBLIOGRAPHY

19 RELEASE VERSION, DATE AND SOURCE

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SNAP CODE : **091006**
091008

SOURCE ACTIVITY TITLE : **Biogas Production**
Other Production of Fuel (Refuse Derived Fuel,...)

A specific methodology for these activities has not been prepared because the contribution to total national emissions is thought to be currently insignificant, i.e. less than 1% of national emissions of any pollutant.

If you have information contrary to this please contact the expert panel leaders.

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SNAP CODE : 091007

SOURCE ACTIVITY TITLE : Latrines

1 ACTIVITIES INCLUDED

This chapter considers ammonia emissions from latrines which are storage tanks of human excreta, located under naturally ventilated wooden shelters.

2 CONTRIBUTION TO TOTAL EMISSIONS

In Poland, the contribution of this activity to total ammonia emissions is about 3%.

Table 1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	SNAP-code*	Contribution to total emissions [%]							
		SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3
Latrines	**091007**	**-**	**-**	**-**	**0**	**-**	**-**	**-**	**0.6**

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported
* = SNAP90 code 090800

3 GENERAL

3.1 Description

A latrine is a simple “dry” toilet built outside the house, usually in a backyard. A storage tank under the latrine can be a hole dug in the ground, or a concrete reservoir. Capacity of the tank can vary between 1 m^3 and 2 m^3, depending on the family size. The time of storage can vary between a few months and “forever”. Tanks are emptied by cesspool emptiers or contents are deposited on an animal manure heap. From time to time chlorinated lime is used for latrines disinfection.

Nitrogen content in human excreta depends on diet, health and physical activity of an individual. A moderately active person with a daily intake of about 300 g of carbohydrates, 100 g of fat and 100 g of proteins excretes about 16 g of nitrogen. Kidneys void 95% of nitrogen and the residual 5% is excreted mostly as N in faeces. A person on European diet voids 80 to 90% of nitrogen as urea (Harper et al, 1983).

Ammonia emissions derive mainly from the decomposition of urea and uric acid. Excreted urea is hydrolysed to NH_3 through the action of microbial urease. The rate of this hydrolysis depends on temperature, pH, amount of urease present and water content. The hydrolysis increases pH of collected urine and faeces to about 9. The decomposition of protein in faeces is a slow process, but during storage, 40 to 70% of total N is converted to the NH_4^+ form (ECETOC, 1994).

Table 2: Daily excretion of nitrogen in normal urine (pH 6.0)

Compound	Quantity [g]	N equivalent [g]
Nitrogen compounds (total)	25 - 35	10 - 14
Urea (50% of solid compounds depends on diet)	25 - 30	10 - 12
Creatinine	1.4 (1 - 1.8)	0.5
Ammonia	0.7 (0.3 - 1)	0.4
Uric acid	0.7 (0.5 - 0.8)	0.2
N in other compounds (e.g. amino acids)		0.5

Source: Harper et al, 1983

Nitrogen is emitted from latrines as NH_3 in a free evaporation process. Ammonia emission from latrines depends on quantity and form of nitrogen compounds in human excreta, as well as on weather conditions.

3.2 Controls

Reduction of ammonia emission from this type of source is possible by installation of water supply and sewage systems, which is possible in particular in towns.

4 SIMPLER METHODOLOGY

As there are no measurements concerning ammonia emission from latrines, only a simpler approach can be used.

5 DETAILED METHODOLOGY

6 RELEVANT ACTIVITY STATISTICS

It is assumed that tenants of urban flats and country houses with no water-flushed toilet have to use latrines outside the house. As it follows from Polish statistical data of 1992, 30% of country houses and 4% of urban flats had no water supply system and 48% of country houses and 14% of urban flats had no water-flushed toilets. The number of people in an average family in town or countryside living together in the same home is needed for estimation of total number of latrines users. Based on that, it was estimated that about 10 million Polish inhabitants (approximately 25% of the population) did not use water- flushed toilets. Changes of that total number during summer holidays is not accounted for.

7 POINT SOURCE CRITERIA

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

It is assumed that during storage of human excreta for one year about 30% of nitrogen is emitted in ammonia form in the free evaporation process. The basis for this assumption was similarity of latrines to open storage of animal manure in lagoons or ponds. Daily N releases per person is 12 gram and the annual N releases is about 4.4 kg, hence the estimated ammonia emission factor per person equals 1.6 kg NH_3 per year.

9 SPECIES PROFILES

10 UNCERTAINTY ESTIMATES

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

In the simpler methodology only one emission factor is available. There is no distinction between children and adults nor between emission factors for summer and winter.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

National totals should be disaggregated on the basis of population, taking urban and rural differences in the number of latrines into account.

13 TEMPORAL DISAGGREGATION CRITERIA

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

17 REFERENCES

ECETOC, 1994. Ammonia Emissions to Air in Western Europe. Technical Report No. 62, ECETOC, Brussels.

Harper, H.A., Rodwell, V.W., Mayes, P.A., 1983. Review of Physiological Chemistry, PZWL, Warszawa (Polish edition).

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Klaassen G., 1991. Past and Future Emissions of Ammonia in Europe, SR 91-01, IIASA, Luxemburg.

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