



National Pollutant Inventory

Emission Estimation Technique Manual

for

**Sewage Sludge and
Biomedical Waste
Incineration**

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**EMISSION ESTIMATION TECHNIQUE MANUAL
FOR
SEWAGE SLUDGE AND BIOMEDICAL WASTE INCINERATION**

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SEWAGE SLUDGE AND BIOMEDICAL WASTE INCINERATION

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1.0 Introduction

The purpose of all Emission Estimation Technique (EET) Manuals in this series is to assist Australian manufacturing, industrial, and service facilities to report emissions of listed substances to the National Pollutant Inventory (NPI). This Manual describes the procedures and recommended approaches for estimating emissions from incineration operations.

EET MANUAL: Sewage Sludge and Biomedical Waste Incineration

HANDBOOK: Waste Disposal Services

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This Manual applies to the following general types of incinerator operation:

- Biomedical waste incineration (both hospital operated incinerators and centralised commercially operated biomedical waste incinerators); and
- Sewage sludge incineration.

No general solid waste incineration facilities, (eg. municipal waste incinerators), were identified in Australia as meeting the NPI reporting thresholds.

It is important to recognise that incineration facilities are frequently part of larger operations (eg. a hospital). If your facility undertakes other activities that could lead to the release of NPI substances, you should refer to the relevant EET Manual for additional information on characterising emissions from these activities. The *NPI Guide*, at the front of this Handbook, provides guidance to help you determine whether your facility or operation is required to report under the NPI.

This Manual was drafted by Dames and Moore in conjunction with the NSW Environment Protection Authority on behalf of the Commonwealth Government.

It has been developed through a process of national consultation involving State and Territory environmental authorities and key industry stakeholders.

2.0 Process Description

Incineration is the process by which materials are burned, producing combustion gases and non-combustible ash residue. The combustion gases are either vented directly to the atmosphere, or to the atmosphere after treatment in air pollution control (APC) equipment. The non-combustible ash residue is removed from the incineration system or air pollution control equipment for disposal.

Two main types of incineration have been identified as operating within Australia (Dames & Moore, 1998). These are:

- Biomedical Waste Incinerators; and
- Sewage Sludge Incinerators.

In general terms the incineration process can be separated into the following key steps:

1. Waste preparation and storage;
2. Waste charging (ie transfer of waste and loading of wastes to incinerator);
3. Waste combustion (including use of supplementary fuel for start-up and maintaining combustion conditions);
4. Treatment of combustion gases and by products (ie APC equipment); and
5. Residue handling and disposal (this includes the handling and disposal of furnace bottom ash, material collected in air pollution control (APC) equipment, and other materials used/consumed in the process eg. scrubber liquor).

A more detailed description of the various incineration types covered by this Manual is provided in Appendix A. Within the two categories of incinerator system considered in this Manual, the main factors that affect the emissions provided from the combustion of a particular waste are:

- combustion system type; and
- air pollution control equipment type and efficiency.

3.0 Emission Estimation

Estimates of emissions of NPI listed substances to air, water and land should be reported for each substance that triggers a threshold. The reporting list and detailed information on thresholds are contained in the *NPI Guide*, included at the front of this handbook.

In general, there are four types of emission estimation techniques (EETs) that may be used to estimate emissions from your facility.

The four types described in *The NPI Guide* are:-

- sampling or direct measurement
- mass balance
- fuel analysis or other engineering calculations
- emission factors

Select the EET (or mix of EETs) that is most appropriate for your purposes. For example, you might choose to use a mass balance to best estimate fugitive losses from pumps and vents, direct measurement for stack and pipe emissions, and emission factors when estimating losses from storage tanks and stockpiles.

If you estimate your emission by using any of these EET's, your data will be displayed on the NPI database as being of 'acceptable reliability'. Similarly, if your relevant environmental authority has approved the use of emission estimation techniques that are not outlined in this handbook, your data will also be displayed as being of 'acceptable reliability'.

This Manual seeks to provide the most effective emission estimation techniques for the NPI substances relevant to this industry. However, the absence of an EET for a substance in this Manual does not necessarily imply that an emission should not be reported to the NPI. The obligation to report on all relevant emissions remains if reporting thresholds have been exceeded.

You are able to use emission estimation techniques that are not outlined in this document. You must, however, seek the consent of your relevant environmental authority. For example, if your company has developed site specific emission factors, you may use these if approved by your relevant environmental authority.

You should note that the EETs presented in this Manual relate principally to average process emissions. Emissions resulting from non-routine events are rarely discussed in the literature and there is a general lack of EETs for such events. However, it is important to recognise that emissions resulting from significant operating excursions and/or accidental situations (eg: spills) will also need to be estimated. Emissions to land, air and water from spills must be estimated and added to process emissions when calculating total emissions for reporting purposes. The emission resulting from a spill is the net emission, ie. the quantity of the NPI reportable substance spilled, less the quantity recovered or consumed during clean up operations.

3.1 Emissions from Incineration Operation

The *NPI Guide* provides guidance to enable you to determine: whether you are required to report under the NPI; what has to be reported; and what substances have to be reported. The purpose of this section is to provide some clarification of these reporting requirements as they apply to incineration operations.

For incinerator facilities, there are two main triggers for reporting. The first relates to the size of the incinerator itself, and whether the throughput of the incinerator exceeds the defined thresholds for Category 2a or 2b substances. Category 2a thresholds are triggered by incinerator activities where 400 tonnes or more of fuel or waste are consumed in the incinerator in a year, or where one tonne or more of fuel or waste is burned in any hour within the reporting year. Category 2b thresholds are triggered by incinerator activities where 2000 tonnes or more of fuel or waste is consumed in an incinerator in a year.

The second trigger for reporting relates to Category 1 substances, where more than 10 tonnes of a Category 1 substance is consumed at a facility in a year, and some of the Category 1 substance may be disposed of by an on-site incinerator. For example, biomedical waste incinerators are common in hospitals. While the 10 tonnes per annum threshold for a Category 1 substance (eg. formaldehyde) is unlikely to be exceeded in terms of incinerator throughput, it is possible that the general hospital activities will lead to 10 tonnes of the Category 1 substance being consumed at the facility. Therefore, in this situation, reporting on emissions of formaldehyde from the incinerator would be required (as part of the overall reporting of emissions from the facility).

The *NPI Guide* at the front of this Handbook lists all of the reportable substances, and the associated thresholds. You should consult this information to determine whether your facility handles, manufactures, or otherwise uses any of the listed substances in excess of the nominated thresholds, and therefore, whether you are required to report emissions of these substances.

It is important to recognise that under the NPI, the following are classed as transfers and are not required to be reported (NEPM, Clause 3.3):

- discharges of substances to sewer;
- deposit of substances into landfill; and
- removal of substances from a facility for destruction, treatment, recycling, reprocessing, recovery or purification.

Due to the nature of the incineration systems that exist in Australia, it is likely that the only reporting requirements that apply for NPI purposes will be for emissions to air. Other releases from incineration operations that may contain NPI listed substances include:

- furnace bottom ash;
- fly ash; and
- scrubber liquor.

However, these releases are tightly controlled by legislation and are required to be sent for disposal to landfills, or to the sewer systems. As noted above, such releases are classed as transfers and are not required to be reported to the NPI. If,

however, the disposal route for these materials does not fall within the definition of transfer, you should seek advice from your State or Territory environment body on whether such substances are to be reported.

Air emissions will arise as **point source emissions** where the gas discharges from the incinerator are exhausted into the atmosphere, generally via some form of air pollution control (APC) equipment and the system's stack or chimney. No other significant sources of air emissions (eg. fugitive emissions) have been identified for well maintained and operated incinerators, with the exception of the handling of sewage sludge prior to being fed into the incinerator. The emissions associated with sewage sludge handling are considered in the EET Manual for Sewage and Wastewater Treatment. The proper storage and handling of ash from the incinerators and the storage of biomedical waste results in negligible air emissions.

There may, however, be fugitive emissions from facilities that are not well maintained and operated. These emissions (if any) are site specific, and there are no published emission factors that can be utilised to characterise these emissions. Under these circumstances, it is your responsibility to determine the quantities of NPI substances released as fugitive emissions and to include these emissions in the total emissions you report under the NPI.

Table 1 (below) lists the Category 2a and 2b substances that are relevant for incinerators. As noted above, the NPI substances for which reporting is required from incinerators are (depending on the size of the facility) the Category 2a and/or Category 2b substances listed in Table 1, together with any Category 1 substances for which a threshold is triggered at the facility.

Table 1. Category 2a and 2b NPI Substances Expected to be Emitted from Solid Waste Incinerators

Category 2a – Substances (from facilities burning more than 400 tonnes per year or more than 1 tonne per hour) ¹	Category 2b – Substances (from facilities burning more than 2000 tonnes per year) ¹
Carbon Monoxide	Category 2A Pollutants
Fluoride Compounds	Arsenic Compounds
Oxides of Nitrogen (NO _x)	Cadmium Compounds
Particulate Matter (PM ₁₀)	Chromium (III) Compounds ²
Polycyclic Aromatic Hydrocarbons	Chromium (VI) Compounds ²
Sulfur Dioxide	Lead Compounds
Hydrochloric Acid	Mercury Compounds
Total Volatile Organic Compounds	Nickel compounds ³
	Beryllium Compounds
	Copper Compounds
	Magnesium Oxide fume
	Polychlorinated dioxins and furans

¹ Note that the throughput (ie. the amount of material burned which is to be used for determining whether reporting is required) is the sum of waste burned, and any fuel used in the incineration process.

² Both Chromium (III) and Chromium (VI) are required to be reported. Limited data is available on the partitioning between Cr (III) and Cr (VI) in incinerator emissions. Where available, guidance is provided in this Manual on the partitioning between these emissions.

³ Nickel carbonyl and nickel subsulfide (both Category 2b substances) are not generally produced by these incinerators. In this situation, these substances should be reported as “zero”. Nickel compounds, however, will need to be reported and suitable emission estimation techniques are provided in this Manual.

3.2 Emission Estimation Techniques in this Manual

As noted in Section 3.1, the only emissions from incinerator facilities that you will be required to report under the NPI are likely to be emissions to air. For most facilities, these will simply be stack emissions but, if a facility has fugitive emissions, these will also need to be reported.

Many incinerator operators are required to undertake periodic monitoring of their emissions (as part of State/Territory licence conditions). If such information is available, you are encouraged to use this information to determine your annual emissions of NPI substances. Section 7.0 provides some general guidance on the use of stack testing data to meet reporting requirements for the NPI, and provides some examples on the use of this data for NPI reporting. In the absence of such monitoring data, this Manual provides other emission estimation techniques to assist you to meet your reporting requirements.

Tables 3 to 7 in this manual provide emission factors to assist you in estimating emissions. Due to the limited amount of Australian data, the emission factors are based on emission factors developed by the US Environment Protection Agency (USEPA). A discussion regarding the basis for these emission factors is given in Section 6. The data relating to the feeds to, and emissions from, Australian sewage sludge incinerators and biomedical waste incinerators are reviewed in Appendix B. The emission factors given in this Manual compare favourably with the measured data, suggesting that the data derived from the

USEPA is suitable as a basis for estimating emissions from incinerators in Australia.

While all techniques contained in this Manual are acceptable methods of estimating your facility's emissions, emission factor ratings have been provided to encourage you to use more accurate emission estimation techniques. A discussion of emission factor ratings is presented in Section 4.0.

The characterisation of emissions from incineration operations is in two parts. The first involves determining emissions from the combustion system ("uncontrolled emissions"), and the second involves modifying these emissions to account for the effectiveness of various pollution controls. Table 2 indicates where EETs for uncontrolled emissions are found in this Manual.

Table 2. Guide to Uncontrolled Emission Factors

Incinerator Type	Pollutant Species		
	Category 1	Category 2a	Category 2b
Biomedical Waste Incinerator	See Section 5.1	Table 4	Table 5
Sewage Sludge Incinerator	See Section 5.1	Table 6	Table 7

The effect of APC on the emission of Category 2a and 2b pollutants is given in Tables 8 and 9 for Biomedical Waste and Sewage Sludge Incineration respectively.

4.0 Emission Factor Rating

A number of the emission factors quoted in this Manual have an associated Emission Factor Rating (EFR) code. The EFRs are based on rating systems developed by the United States Environmental Protection Agency (USEPA), and by the European Environment Agency (EEA). The EFR codes have been provided to give some indication of the reliability of the emission factor. It is essential to recognise that the EFRs cited are not necessarily applicable to Australian facilities, as they have been developed for overseas industry. However, the EFRs are useful in providing some general indication of emission factor reliability.

Sources for all emission factors cited can be found in the Section 8.0 of this document. The emission factor ratings will not form part of the public NPI database.

When using emission factors, you should be aware of the associated EFR code and what that rating implies. An A or B rating indicates a greater degree of certainty than a D or E rating. The less certainty, the more likely that a given emission factor for a specific source or category is not representative of the source type. These ratings notwithstanding, the main criterion affecting the uncertainty of an emission factor remains the degree of similarity between the equipment/process selected in applying the factor, and the target equipment/process from which the factor was derived.

The EFR system is as follows:

A	-	Excellent
B	-	Above Average
C	-	Average
D	-	Below Average
E	-	Poor
U	-	Unrated

5.0 Emission Factors

The discussion in the following sections primarily relates to the use of default emission factors for the characterisation of emissions.

5.1 Category 1 Pollutants

The following discussion applies to both biomedical and sewage sludge incinerator facilities.

The amount of a Category 1 substance that may be fed to the incinerator can be estimated by sampling the feed to the incinerator, or by using a mass balance for the facility, eg. a hospital.

In using the first of these methods (ie sampling the feed), it is important that representative sample(s) are taken, and that the sample is appropriately handled and analysed. The total amount of a Category 1 substance fed to the incinerator is the product of the flow of total waste to the incinerator by the concentration of the Category 1 substance in the waste. (In using this method it is important to ensure there is consistency in the units of flow and concentration). It is also important to note that the feed to an incinerator is likely to be heterogeneous and, as a consequence, multiple samples may be required to fully characterise variations in incinerator throughput.

The mass balance approach requires consideration by the facility of the amount of Category 1 substance in raw materials and/or generated on site from the process, and the potential disposal routes for the substance. For example, a solvent may be used in a hospital where the majority of it is disposed to a solvent recycler. The difference between what is bought into the hospital, and what is disposed to the recycler, may represent the amount of solvent in the biomedical waste stream from the hospital, ie:

$$\text{Solvent in} = \text{Solvent out to recycler} + \text{Solvent in waste stream.}$$

5.1.1 Non-halogenated Hydrocarbons

The principal Category 1 substances that may require reporting are non-halogenated hydrocarbons eg. acetone, glutaraldehyde. Combustion conditions in both biomedical and sewage sludge incinerators lead to high destruction efficiencies (typically 99.99%) of these compounds (Brunner, 1989).

Therefore, assuming a typical destruction efficiency of 99.99%, the uncontrolled emission factor for these compounds is:

$$0.1\text{kg/tonne of Category 1 substances fed to Incinerator.}$$

5.1.2 Halogenated Hydrocarbons

For some sewage treatment plants the quantity of halogenated hydrocarbons (eg. trichloroethylene) may exceed the Category 1 reporting threshold. Halogenated hydrocarbons are typically more difficult to destroy in combustion systems resulting in slightly lower destruction efficiencies (typically 99.95%) for these compounds (Brunner, 1989).

Therefore, assuming a typical destruction efficiency of 99.95%, the uncontrolled emission factor for these compounds is:

0.5 kg/tonne of Category 1 substance fed to the Incinerator.

5.1.3 Metals

A number of metals, notably cobalt, antimony, manganese, selenium and zinc are defined as Category 1 substances (but are not Category 2a or 2b substances). It is considered unlikely that the Category 1 criteria will be met for sewage sludge or biomedical waste incinerators in Australia. However, if the Category 1 reporting threshold is met for the whole facility (eg the sewage treatment plant), the following uncontrolled emission factors apply to these incinerators. The effects of various air pollution controls on these emissions is discussed in Section 5.3.

Table 3. Category 1 – Uncontrolled Metal Pollutant Emission Factors

Metal	Biomedical Waste ¹ (kg of pollutant/ tonne of dry waste fed to incinerator)	Sewage Sludge ² (kg of pollutant/ tonne of dry waste fed to incinerator)	Emission Factor Rating
Cobalt	N/A	0.009	C
Antimony	0.00639	0.0015	D/E
Nickel	0.000295	0.008	B
Manganese	0.000284	0.0094	C
Selenium	N/A	0.00015	D

N/A = Not Available

¹ USEPA, July 1996, Section 2.3

² USEPA, July 1996, Section 2.2

If information is available on the composition and quantity of the feed to the incinerator, and the composition and quantity of bottom ash produced, this information could be used to estimate uncontrolled emissions in preference to the default uncontrolled emission factors presented in Table 3. In such situations, it is assumed that all of the metals in the feed to the incinerator are either in the collected ash or emitted as part of the flue gas. In simple terms:

$$\text{Mass of metal fed to incinerator} = \text{Mass of metal in ash} \\ + \text{Mass of metal emitted to air}$$

It is essential to recognise that the emission values obtained when using mass balance techniques are only as good as the values used in performing the calculations. For example, small errors in data or calculation parameters can result in large errors in the final emission estimates. In the specific context of estimating emissions from incinerators, the failure to use representative samples (or where feedstock is highly variable in composition) could lead to significant

uncertainty in the predicted emissions.

5.1.4 Others

No other Category 1 compounds have been identified that are likely to be in sewage sludge or biomedical waste incineration.

5.2 Category 2 Substances

5.2.1 Biomedical Waste Incineration

Tables 4 and 5 provide uncontrolled emission factors for Category 2a and 2b substances from biomedical waste incinerators. The effect of APC on these emissions is discussed in Section 5.3.

Table 4. Uncontrolled Emission Factors for Category 2a Substances from Biomedical Waste Incinerators

Category 2a Substance	Emission Factor ¹ (kg of pollutant/ tonne of dry feed to the incinerator) ²	Emission Factor Rating
Carbon Monoxide (CO)	1.48	A
Fluoride Compounds	0.0743	D
Oxides of Nitrogen (NO _x)	1.78	A
Particulate Matter (PM ₁₀) ⁴	2.33	B
Polycyclic Aromatic Hydrocarbons ³ (PAHs)	0.05	E
Sulfur Dioxide ³ (SO ₂)	1.09	B
Hydrochloric Acid (HCl) ⁵	16.8	C
Total Volatile Organic Compounds	0.15	B

¹ USEPA, July 1996, AP42 Section 2.3, with the exception of PAHs

² Feed to the incinerator should include waste and fuel

³ See Section 6 for further explanation of the derivation of these emission factors

⁴ The emission factor given is described in USEPA (1996) as for Total Particulate Matter. For typical Biomedical Incinerators PM₁₀ represents greater than 90% of Total Particulate Matter (Hasselriis 1990) and, therefore, in the absence of other information, the emission factor quoted above may be taken as being a reasonable, if slightly conservative, emission factor.

⁵ Based on average %Cl in biomedical waste (Walker & Copper, 1992).

For the estimation of the uncontrolled emissions of fluoride, hydrochloric acid and sulfur dioxide, a mass balance approach can also be used, as these compounds are neither created nor destroyed by the incinerator. In using the mass balance approach to estimate hydrochloric acid and sulfur dioxide emissions, the quantity of chlorine and sulfur in the feed can be used to estimate the quantity of chlorine and sulfur in the stack emission. Due to the oxidation of sulfur compounds in the incinerator, the mass of sulfur dioxide emitted is twice the sulfur fed to the incinerator.

Table 5. Uncontrolled Emission Factors for Category 2b Substances from Biomedical Waste Incinerators

Category 2b Substance	Emission Factor ¹ (kg pollutant/tonne of dry waste to incinerator)	Emission Factor Rating
Arsenic Compounds	0.000121	B
Cadmium Compounds	0.00274	B
Chromium Compounds ²	0.000388	B
Lead Compounds	0.0364	B
Nickel Compounds	0.000295	B
Mercury Compounds	0.0537	C
Beryllium Compounds	0.00000312	D
Copper Compounds	0.00624	E
Polychlorinated dioxins and furans	0.0000465	E

0

¹ USEPA, July 1996, AP42 Section 2.3

² The emission factor quoted is for total Chromium (ie. Cr(III) and Cr(VI)). Cr(VI) is typically 10-20% of total chromium emissions (Glassner, et al, 1991).

As with the Category 1 metals (Section 5.1.3), a mass balance approach can be used to estimate uncontrolled metal emissions.

5.2.2 Sewage Sludge Incineration

Tables 6 and 7 provide uncontrolled emission factors for Category 2a and 2b substances respectively. The effect of APC on these emissions factor is discussed in Section 5.3.

Table 6. Uncontrolled Emission Factors for Category 2a Substances from Sewage Sludge Incinerators.

Category 2a Substance	Emission Factor ¹ (kg of pollutant/ tonne of dry waste feed to the incinerator)	Emission Factor Rating
Carbon Monoxide (CO)	15.5	C
Fluoride Compounds	N/A	
Oxides of Nitrogen (NO _x)	2.5	C
Particulate Matter (PM ₁₀)	4.1	B
Polycyclic Aromatic Hydrocarbons ² (PAHs)	0.05	E
Sulfur Dioxide ² (SO ₂)	14.0	B
Hydrochloric Acid (HCl) ³	0.03	E
Total Volatile Organic Compounds	0.84	D

¹ USEPA, July 1996 AP42 Section 2.2, with the exception of PAHs

² See Section 6 for further explanation of these emission factors

³ Based on controlled emission data in AP42 and control efficiency of 70% (see Table 8).

As discussed in Section 5.2.1, uncontrolled emissions for some of the above Category 2a substances can also be assessed by using a mass balance approach.

Table 7. Uncontrolled Emission Factors for Category 2b Substances from Sewage Sludge Incinerators

Pollutant	Emission Factor ¹ (kg of pollutant/tonne of dry waste feed to the incinerator)	Emission Factor Rating
Arsenic Compounds	0.0047	B
Cadmium Compounds ²	0.016	B
Chromium Compounds	0.014	B
Lead Compounds	0.050	B
Nickel Compounds	0.008	B
Mercury Compounds	0.0023	C
Beryllium Compounds	0.00015	E
Copper Compounds	0.040	B
Magnesium Oxide fume	0.140	C
Polychlorinated dioxins and furans	0.00000465	E

¹ USEPA, July 1996 AP42 Section 2.2

² Emission factor for chromium is for total chromium (Cr(III) and Cr(VI)), Cr(VI) is typically 10-20% of total chromium emissions (Glassner, et al, 1991).

As with the Category 1 metals (Section 5.1.3), a mass balance approach can be used to estimate uncontrolled metal emissions.

5.3 Abatement Technologies For Incinerators

A number of Air Pollution Control (APC) devices are available to collect the range of pollutants emitted from incinerators. The effectiveness of these devices is characterised as control efficiency, ie. the % of the uncontrolled emission which is collected. Tables 8 and 9 provide typical control efficiencies for APC devices. The control efficiency of a particular APC device is determined by a range of site-specific engineering and operational considerations. The control efficiencies

given are based on a consolidation of manufacturers data, measured data, other reported data and in the case of control efficiencies for metals, the physical characteristics eg. metal vapour pressure. As such, the control efficiencies represent a “typical” control efficiency. (The principal sources of data are the references listed in Section 8.0).

To determine the emission factor for a compound with a given control efficiency, the emission factor is the uncontrolled emission factor, multiplied by one minus the control efficiency ie.:

$$\text{Controlled Emission} = \text{Uncontrolled Emission} \left(1 - \frac{\% \text{Control Efficiency}}{100}\right)$$

5.3.1 Category 1 Pollutants

Standard APC designed specifically for the control of particulate material (ie. fabric filters and ESPs), do not significantly affect emission of non-halogenated and halogenated hydrocarbons.

The control efficiencies for Category 1 metals are similar to the Category 2b metals (see Table 9). The control efficiencies for antimony, cobalt and manganese emissions are similar to those for chromium and lead. Control efficiencies for selenium are similar to those for cadmium.

5.3.2 Category 2a and 2b Substances

Air Pollution Controls (APCs), such as baghouses and cyclones, are often used to reduce emissions from incinerators of Category 2a and 2b substances. Tables 8 and 9 provide expected control efficiencies for commonly used APCs.

Table 8. APC Control Efficiencies for Category 2a Substance

Pollutant	APC Type	Control Efficiency %
Carbon Monoxide	None identified	0
Fluoride Compounds	Wet scrubber – water	70
	Wet scrubber – caustic	96
Oxides of Nitrogen	None identified	0
Particulate matter	Cyclone	65
	Fabric filter	98
	Electrostatic Precipitator (ESP)	97
	Wet Scrubber -Venturi	95
PAHs	Fabric filters	50
SO ₂	Wet scrubber – water	30
	Wet scrubber – alkali	93
HCl	Wet scrubber – water	70
	Wet scrubber – alkali	96
Total Volatile Organic Compounds	None identified	0

Table 9. APC Control Efficiencies for Category 2b Pollutants

Pollutant	APC Type	Control Efficiency %
Chromium, Nickel Beryllium, Copper, Lead	Fabric filter	95
	ESP	90
	Venturi quench/ Venturi scrubber	90
Cadmium	Fabric filter	92
	ESP	88
	Venturi quench/ Venturi scrubber	88
Arsenic, Mercury Magnesium oxide	Fabric filter	30
	ESP	25
	Venturi quench/ Venturi scrubber	50
Polychlorinated Dioxins & Furans	Fabric filter	50
	Venturi quench/ Venturi scrubber	50

6.0 Assumptions and Discussion

The emission factors presented in this manual have been based on emission factors developed by the US Environmental Protection Agency. These emission factors are supplemented by other information, including Australian data, where available. The sections below discuss the assumptions made in determining which emission factors could be used for Australian operations.

6.1 Category 1 Substances

6.1.1 Non-halogenated Hydrocarbons

The destruction efficiency of hydrocarbons in incineration systems depends primarily on the combustion temperature, excess oxygen content, and residence time in the combustion system. Destruction efficiencies of greater than 99.99% are typical for hydrocarbon in incinerators, where combustion temperatures are greater than 950_C, in 2% excess O₂, and with a residence time of two seconds (Brunner, 1989). These combustion conditions are typical of combustion conditions in both biomedical and sewage sludge incinerators (Brunner, 1989 and USEPA, 1996).

Due to the volatility of these hydrocarbons downstream, the APC conventionally used in Australian incinerators do not significantly affect emissions.

6.1.2 Halogenated Hydrocarbons

As with non-halogenated hydrocarbons, the destruction of halogenated hydrocarbons depends on combustion temperature, residence time and oxygen content. Higher temperatures (approximately 1200 °C) are usually required for the destruction of these hydrocarbons. The exact destruction efficiency varies depending on the halogenated hydrocarbon. However, 99.95% destruction is considered appropriate for destruction efficiencies in biomedical and sewage sludge incinerators (Brunner, 1989).

Due to the volatility of these hydrocarbons downstream, the APC conventionally used in Australian incinerators are considered not to significantly affect emissions.

6.2 Category 2a and 2b Substances

6.2.1 Category 2a Substances

Uncontrolled emission factors for most of the Category 2a and 2b substances are based on USEPA emission factors. As indicated in Section 5, the emission factor

rating for these uncontrolled emissions is generally above average and is considered to provide a good basis for estimating emissions.

The USEPA also have emission factors for controlled emissions based on different configurations of APC. Due to the limited amount of data, the emission factor rating for these “controlled emission” factors is generally poor. While the specific performance (and, hence, control efficiency) of APC equipment can vary from the defaults provided in Tables 8 and 9, the use of APC efficiencies in conjunction with uncontrolled emission factors is considered a more transparent and easier method for determining “controlled emission” factors.

Carbon monoxide

Carbon monoxide emission factors are consistent with destruction efficiencies of 99.99%, although combustion efficiency (ie % complete combustion) for sewage sludge is less than that for biomedical waste, principally because of the nature of the waste (ie. higher water content).

PAHs

The USEPA does not provide emissions factors for Polycyclic Aromatic Hydrocarbons (PAHs). These emissions are primarily related to the combustion efficiency of the incinerator (in particular, carbon monoxide emissions) and are typically expected to be approximately 0.005% by weight of the feed to the incinerator. The figure 0.005% is expected to provide a conservative estimate of PAH emissions in the absence of any other information.

Sulfur Dioxide

The sulfur dioxide (SO₂) emission factors given in Tables 4 and 6 are based on USEPA emission factors. The use of supplementary fuel to maintain combustion temperatures can contribute to sulfur dioxide emissions. With fuels such as natural gas or LPG, the sulfur content of the fuel is generally very low, and the use of these fuels does not significantly affect sulfur dioxide emissions.

To consider additional sulfur dioxide emissions from any supplementary fuel, the following emission factor should be used:

20 y kgs SO₂/tonne of fuel burnt, (where y is the mass % sulfur in the fuel)

Hydrochloric Acid

The quoted emission factor for hydrochloric acid (HCl) emissions from biomedical waste incineration is 16.8 kgs/tonne of waste. This corresponds to the chlorine content in the waste of between 1-2%, which is consistent with analysis of biomedical waste (Walker and Copper, 1992).

6.2.2 Category 2b Substances

The Category 2b substances of relevance to incineration are primarily heavy metals. These are not ‘destroyed’ by the combustion process, and are either

collected in bottom ash in the incinerator, collected in APC equipment, or emitted to the atmosphere. Therefore, metal emissions primarily depend on the metal content of the waste, and mass balances can be used to determine heavy metal emissions. The breakdown of emissions to ash, APC or atmosphere is usually denoted as metal partitioning. This partitioning depends on the volatility of the heavy metal. The chlorine content of the waste can significantly affect metal volatility, especially for lead and copper. However, as chlorine levels in both biomedical waste and sewage sludge are relatively low, the effect of chlorine on metal volatility is not expected to be significant.

The metal content of sewage sludge can vary significantly between sewage treatment plants. This is often because of the mix of industrial, commercial and residential areas the treatment plant serves. For biomedical waste incineration, the primary source of heavy metals are those used in the plastics (eg. cadmium compounds) as a colouring agent. Mercury in waste can also vary between incinerators, depending on the quantity of waste from dental facilities.

6.2.3 Air Pollution Control (APC) Efficiencies

APC efficiencies vary with the type of pollution control equipment and the pollutant being considered. Pollution control efficiencies are usually expressed as ranges, with typical values given in Tables 8 and 9.

In Australia, wet scrubbers are typically used to control acid gas emissions, (including the NPI listed substances: HCl, SO₂ and Fluoride compounds). Scrubber efficiencies are generally high but may be higher than those given in Section 5.3, in particular for SO₂, if a caustic scrubbing solution is employed. However, the default control efficiencies given in Section 5.3 should be used unless other site specific data are available.

Particulate collection efficiencies of APCs depend on the particle size distribution of the particulate matter from the combustion chamber. As a similar incinerator concept is used, particulate matter from both biomedical waste and sewage sludge incinerators is commonly between 1.0 μ m to 10 μ m. As given in Table 8, high control efficiencies are achieved with the APC typically used on these incinerators.

The effectiveness of APCs for volatile heavy metals depends on the temperature at which the APC operates. Fabric filters and Electrostatic Precipitators (ESP) usually operate at relatively high temperatures, and are less effective than those which operate at a lower temperature. The volatile heavy metals usually condense to form a fume (<2 μ m) that is only partially collected by APC equipment, and hence, lower control efficiencies are applied to the more volatile heavy metals.

7.0 Monitoring

Many facilities conduct monitoring as part of the existing regulatory requirements. Typically, the monitoring is tied directly to the conditions on an environmental licence and will vary from site to site.

It is important to recognise that facilities also collect a range of other information beyond stack or liquid effluent testing that may be used in characterising emissions for the NPI. Typical data collected include:

- volumetric flow rates (eg products, wastes, wastewater treatment);
- mass flowrates;
- stream composition;
- product and waste composition; and
- production and waste quantities.

In most situations, the use of such data as a basis for calculating emissions will provide the most representative emissions information for a facility and should be used, where available, in calculating emissions.

Monitoring data can be expressed in many different units. The following discussion may be of assistance when converting monitoring results into annual emission estimates for the purposes of the NPI. It is important to remember that the calculation of annual emissions must also take account of the number of hours per year the source is discharging to the environment.

Stack data is typically presented in terms of either actual flow or a “normalised” flow. The difference is that normalised data is standardised to a particular temperature and pressure, which are typically 0_C and 1 atm respectively. However, sometimes it may be referenced to 25_C and 1 atm. The following terms may be used when presenting data:

- acm – actual cubic metre (at actual temperature and pressure);
- scm – standard cubic metre (typically at 25_C and 1 atm, although sometimes it may be at 20_C or even 0_C); and
- Nm³ – normal cubic metre (typically at 0_C and 1 atm).

It is essential to ascertain under what conditions the source test data is presented before determining annual emission estimates. Two examples of the use of sampling data to characterise annual emissions are presented below. Example 1 is where the concentration of the compound is presented at the same conditions as the measured flow rate, while Example 2 is where the concentration and flue gas flows are measured under different conditions.

Example 1

The following example illustrates how the concentration of copper is known as the same conditions as the measured flow rate.

The following data is known:

- the flue gas flow from a stack is measured at 30 Nm³/sec;
- the measured concentration of copper compounds in the flue gas is 0.01 mg/Nm³; and
- the stack operates 24 hours per day for 300 days per year.

First of all, the number of seconds per year the stack is emitting is determined:

$$\begin{aligned}\text{No. seconds/year} &= (3600\text{sec/hour}) \times (24\text{hours/day}) \times (300\text{days/year}) \\ &= 2.6 \times 10^7 \text{ seconds/year}\end{aligned}$$

Using this data the emission is derived as follows:

$$\begin{aligned}\text{Emission} &= (30\text{Nm}^3/\text{sec}) \times (0.01\text{mg}/\text{Nm}^3) \times (2.6 \times 10^7 \text{ sec/year}) \\ &= 7.8 \text{ kg of copper compounds per year.}\end{aligned}$$

Example 2

If the copper concentration and flue gas flows are measured under different conditions, then additional calculations are required. For example, the following data is known:

- the flue gas flow from a stack is measured at 100 acm/sec;
- the measured concentration of copper compounds in the flue is 0.01 mg/Nm³;
- the stack operates 24 hours per day for 300 days per year; and
- the conditions at the stack tip are approximately 150_C and 1 atm.

Using the actual stack data, the 'actual' flue gas flow can be converted to a normalised flow using a ratio of temperatures. Note: however that the temperatures must be presented using the absolute temperature scale of Kelvin (ie. 0_C = 273 K). The conversion is then performed as follows (noting that the actual stack temperature conditions are 150c + 273 = 423 K):

$$\begin{aligned}\text{Flue gas (Nm}^3/\text{sec)} &= 100 \text{ acm/sec} \times (273/423) \\ &= 64.5 \text{ Nm}^3/\text{sec}\end{aligned}$$

The emission rate is then derived using the same methodology as outlined in Example 1 as follows:

$$\begin{aligned}\text{Emission} &= (0.01\text{mg}/\text{Nm}^3) \times (64.5\text{Nm}^3/\text{sec}) \times (2.6 \times 10^7 \text{ sec/year}) \\ &= 16.8 \text{ kg of copper compounds per year.}\end{aligned}$$

8.0 References

1. Barton, R.G., Clark, W.D. and W.R. Seeker, *Fate of Metals in Combustion Systems*, Combust. Sci and Tech, Proc. First Ind. Cong. on Toxic Combustion Byproducts, pp327-342, 1990.
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APPENDIX A

Incinerator Industry Description

The following is an overview of the incineration industry in Australia. It is based on discussions/liaison with Australian Incinerator Operators and Information (Dames & Moore, 1998) from the USEPA (USEPA, 1996).

A.1 Biomedical Waste Incinerators

In Australia, biomedical waste incinerators may be subdivided into the following two generic categories:

1. Hospital operated incinerators: and
2. Centralised commercially operated biomedical waste incinerators.

The types of waste incinerated include a heterogeneous mix of some, or all, of the following:

- Human anatomical;
- Plastics;
- Swabs, absorbents;
- Alcohol, disinfectants;
- Animal infected anatomical;
- Glass;
- Bedding, shavings, paper, fecal matter;
- Gauze, pads, swabs, garments, paper, cellulose;
- Plastics, PVC, syringes;
- Sharps, needles; and
- Fluids, residuals.

Controlled-air incineration is the most widely used biomedical waste incinerator (MWI) technology and dominates the market for new systems at hospitals and similar medical facilities. This technology is also referred to as starved-air incineration, two-stage incineration, or modular combustion.

Combustion of waste in controlled air incinerators occurs in two stages. In the first stage, waste is fed into the primary, or lower, combustion chamber, and is operated with less than the stoichiometric amount of air required for combustion. Combustion air enters the primary chamber from beneath the incinerator hearth (below the burning bed of waste). This air is called primary, or under fire air. In the primary (starved-air) chamber, the low air-to-fuel ratio dries, facilitates volatilisation of the waste, and most of the residual carbon in the ash burns. With these conditions, combustion gas temperatures are relatively low (760 to 980 °C).

In the second stage, excess air is added to the volatile gases formed in the primary chamber to complete combustion. Secondary chamber temperatures are higher than primary chamber temperatures, typically 980 to 1,095_C, and these temperatures are maintained for 1-2 seconds. Depending on the heating value and moisture content of the waste, additional heat input may be needed. This can

be provided by auxiliary burners, located at the entrance to the secondary (upper) chamber, to maintain desired temperatures.

Waste feed and ash removal can be manual or automatic, depending on the unit size and options purchased.

In Australia, Biomedical Waste Incinerators have a number of different air pollution control (APC) equipment configurations. The APC equipment found on Australian incinerators includes:

- wet scrubbers to remove acid gases and particulate;
- fabric filters to remove particles; and
- electrostatic precipitators (ESPs).

Wet scrubbers use gas-liquid absorption to transfer pollutants from a gas to a liquid stream. The scrubber design, and the type of liquid solution used largely determine contaminant removal efficiencies. With plain water, removal efficiencies for acid gases could be as high as 70 percent for HCl, and 30 percent for SO₂ (ie. acid gases). The addition of an alkaline reagent to the scrubber liquor for acid neutralisation has been shown to result in removal efficiencies of 93 and 96 percent. The types of wet scrubbers used include:

1. Low-energy scrubbers (spray towers). These are primarily used for acid gas (HCl and SO₂) control only, and are usually circular in cross section. The liquid is sprayed down the tower through the rising gas. Acid gases are absorbed/neutralised by the scrubbing liquid. Low-energy scrubbers mainly remove particles larger than 5-10 micrometers (µm) in diameter.
2. Medium-energy scrubbers. These can be used for particulate matter and/or acid gas control. Medium energy devices rely mostly on impingement to facilitate the removal of particulate matter. This can be accomplished through a variety of configurations, including packed columns, baffle plates and liquid impingement scrubbers.
3. Venturi scrubbers. These are high-energy systems used primarily for particulate matter control. A typical Venturi scrubber consists of converging and diverging sections connected by a throat section. A liquid (usually water) is introduced into the gas stream upstream of the throat. The flue gas impinges on the liquid stream in the converging section. As the gas passes through the throat, the shearing action atomises the liquid into fine droplets. The gas then decelerates through the diverging section, resulting in further contact between particles and liquid droplets. The droplets are then removed from the gas stream by a cyclone, demister or swirl vanes.
4. A fabric filtration system (baghouse). This consists of a number of filtering elements (bags), along with a bag cleaning system contained in a main shell structure with dust hoppers. Particulate-laden gas passes through the bags so that the particles are retained on the upstream side of the fabric, thereby cleaning the gas. Fabric filters can achieve very high (>99.9 percent) removal efficiencies for particulate matter. These systems are also very effective in

controlling fine particulate matter, also resulting in the control of metals and organics entrained on fine particulate.

5. Particulate collection in an Electrostatic Precipitator (ESP). This occurs in 3 steps: (a) suspended particles are given an electrical charge; (b) the charged particles migrate to a collecting electrode of opposite polarity; and (c) the particulate matter is dislodged from the electrodes, and collected in hoppers for disposal.

ESPs have been used in many applications because of their high reliability and efficiency in controlling total particulate matter emissions. Except for those ESPs that are very large and carefully designed, however, they are generally less efficient than baghouses in the control of fine particulates and metals.

A.2 Sewage Sludge Incinerators

The two main types of sewage sludge incineration systems are:

A.2.1 Multiple Hearth Furnaces

The basic multiple hearth furnace (MHF) is a vertically oriented cylinder. In most MHFs, partially de-watered sludge is fed onto the perimeter of the top hearth. The rabble arms move the sludge through the incinerator by raking the sludge toward the centre shaft where it drops through holes located at the centre of the hearth. In the next hearth, the sludge is raked in the opposite direction. This process is repeated in the subsequent hearths. The effect of the rabble motion is to break up solid material to allow better surface contact with heat and oxygen. A sludge depth of about 3 centimetres is maintained in each hearth at the design sludge flow rate.

The MHF incineration process, multiple hearth furnaces can be divided into three zones. The upper hearths comprise the drying zone where most of the moisture in the sludge is evaporated. The temperature in the drying zone is typically between 425 and 760_C. Sludge combustion occurs in the middle hearths (second zone) as the temperature is increased to about 925_C. The combustion zone can be further subdivided into the upper-middle hearths where the volatile gases and solids are burned, and the lower-middle hearths where most of the fixed carbon is combusted. The third zone, made up of the lowermost hearth(s), is the cooling zone. In this zone the ash is cooled as its heat is transferred to the incoming combustion air.

MHF are sometimes operated with afterburners to further reduce odours and concentrations of unburned hydrocarbons. In after burning, furnace exhaust gases are ducted to a chamber where they are mixed with supplemental fuel and air, and completely combusted.

A.2.2 Fluidised Bed Incinerators

Fluidised bed combustors (FBCs) consist of a vertically oriented outer shell constructed of steel and lined with refractory. Tuyeres (nozzles designed to deliver blasts of air) are located at the base of the furnace within a refractory-lined grid.

Partially de-watered sludge is fed into the lower portion of the furnace. Air injected through the tuyeres, at pressures ranging from 20 to 35 kilopascals, simultaneously fluidises the bed of hot sand and the incoming sludge. Temperatures of 750 to 925_C are maintained in the bed. Residence times are typically two to five seconds. As the sludge burns, fine ash particles are carried out the top of the furnace.

Combustion of the sludge occurs in two zones. Within the bed itself (Zone 1), evaporation of the water and pyrolysis of the organic materials occur nearly simultaneously as the temperature of the sludge is rapidly raised. In the second

zone (freeboard area), the remaining free carbon and combustible gases are burned. The second zone functions essentially as an afterburner.

A.2.3 Air Pollution Control Systems

Particulate emissions from sewage sludge incinerators have historically been controlled by wet scrubbers, since the associated sewage treatment plant provides both a convenient source, and a good disposal option for the scrubber water.

The types of sewage sludge incinerator controls range from low pressure drop spray towers and wet cyclones, to higher pressure drop Venturi scrubbers and Venturi/impingement tray scrubber combinations. The most widely used control device applied to a multiple hearth incinerator is the impingement tray scrubber.

A.3 References

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APPENDIX B

Comparison of EET Estimates with Australian Data

B.1 Introduction

Little data exists on emissions of NPI substances from Australian incinerator facilities. Usually, license conditions stipulate pollutant concentrations exiting from the stack, rather than absolute emissions. Therefore, to compare NPI emission factors with measured results requires details of stack velocities, temperatures, cross sectional areas and incinerator throughput at the time of measurement. These data are seldom available.

B.2 Comparison With Biomedical Waste Incinerator Data

Two limited sets of data have been obtained by Dames & Moore as part of the development of the NPI Handbook (see Tables B1 and B2 below). The data provided by the respective incinerator operators has been provided on a confidential basis. The reported data were measured using standard sampling techniques.

A comparison of the emissions from a small hospital incinerator (nominal throughput 86 kg/hr) is given below.

Table B.1. Comparison of PM₁₀ and HCl Emissions from a Small Biomedical Waste Incinerator (Uncontrolled)

Pollutant	Emission Estimate ¹ (kg/tonne of dry waste)	Measured Results (kg/tonne of waste) ²	
		Test 1	Test 2
PM ₁₀	2.33	6.15	3.0
HCl	16.8	11.25	19.5

¹ See Table 4 of this Manual.

² Source: Confidential.

The emission factors for both particulate matter and HCl compare favourably with measured data.

The other data available on biomedical waste incineration considers the removal efficiency of a two stage scrubbing system involving caustic scrubbing on a large biomedical waste incinerator (nominal capacity 16,800 kg/hr). The results are given in Table B2.

Table B.2. Comparison of Measured and EET Manual Assumed Control Efficiencies for a Large Biomedical Waste Incinerator

Pollutant	Assumed Control Efficiency (%)	Measured Control Efficiency ² (%)
PM ₁₀	95	0
HCl	96	98.4
NO _x	0	0
Mercury (Hg)	50	45
Dioxins and Furans	50	66.7

¹ See Tables 8 and 9 of this Manual.

² Source: Confidential

The measured control efficiencies and those provided in this Manual compare favourably for HCl, NO_x dioxins, furans and mercury. The collection efficiency suggested in this Manual for particulate removal is higher than that measured. From the data available, it is not possible to ascertain the reason for this difference.

B.3 Comparison with Sewage Sludge Incinerator Data

A comparison of the uncontrolled emissions from a multi-hearth sewage sludge incinerator using the emission factors presented in this Manual, and the emissions estimated based on average metal concentrations of sewage sludge is given below.

Table B.3. Comparison of Predicted Uncontrolled Metal Emissions for a Sewage Sludge Incinerator and EET Estimates

Source	Pollutant						
	As	Cd	Cr (Total)	Cu	Pb	Hg	Ni
Glenfield STP ³	1.4	6	141	900	192		36
ATLAS ⁴		3		500	200	3	40
Wollongong STP ⁵	6.45	6.10	569	2036	147	2.83	95
Shellharbour STP ⁵	4.27	3.15	34	863	105	1.82	19
Cronulla STP ⁶	5.5	3.9	214.3		294	7.1	65
Malabar ⁶	6.7	15	375.6		316	5.3	162
Quakers Hill ⁶	5.0	1.4	51.5		63	3.1	23
Malabar ⁷		4.3	178	381		4	72
Average Sludge Concentration ⁸ (g/tonne)	5.6	5.3	240	950	188	4.0	64
Assumed % Emitted to Air ¹	95	98	10	11	42	96	10
Estimated Uncontrolled Emissions (kg/tonne of dry waste)	0.0053	0.0052	0.024	0.10	0.079	0.0039	0.0064
EET Estimate ² (kg/tonne of dry waste)	0.0047	0.016	0.014	0.04	0.05	0.0023	0.008

¹ Based on metal partitioning (ie. % of metal collected in bottom ash) given in Barton *et al* 1990.

² Tables 3 and 7 of this Manual

³ Awad, et al, 1989

⁴ Mathews, 1996

⁵ Cox and Whelan, 1996

⁶ Turner, et al, 1996

⁷ Water Board, 1989.

Based on the estimates in this Manual, the estimated pollutant emissions compare favourably with those derived from average measured sludge quality data. As is apparent from the measured sludge quality data, there is significant variability in the quality of sewage sludge, reflecting the nature of the catchment for the treatment plant.

Trial studies were also undertaken as part of a review of sewage sludge disposal options for sludge collected at the Malabar Sewerage Treatment Plant (Water Board, 1989). A trial was undertaken to consider the emissions from a multi-hearth incinerator with a wet scrubber. A comparison of measured emission rates and those estimated in this EET Manual is given below.

Table B.4. Comparison of Measured Emission Rates with EET Estimates for Sewage Sludge Incinerators

	Pollutant						
	Cr	Cd	Cu	Hg	NO _x	SO ₂	Particulates
Measured Emission ¹ (kg/tonne of sludge)	0.0008 1	0.0008 1	0.0004 5	0.063	0.99	0.126	1.08
EET Estimate ² (kg/tonne of sludge)	0.0014	0.0019 2	0.004	0.0011 5	2.5	9.8	2.6

¹ Water Board, 1989.

² Tables 6 and 7 of this Manual.

With the exception of mercury, the EET Manual emission factors compare favourably with those measured during this trial. Because of the nature of the industry upstream from the sewage treatment plant, it is likely that the plant did receive a higher than average mercury input. The accuracy of other pollutant estimates varied with most estimates within a factor of 2-3 of the measured valued. As the measured database is limited, this level of discrepancy between measured and predicted is not to be unexpected.

B.4 Summary of Comparison

Little data is available to allow direct comparisons between measured Australian pollutant emissions, and those predicted by the emission factors in the EET Manual. However, the limited data that is available indicate that the measured data compares favourably with USEPA uncontrolled emission factors data and suggests that the US derived data is suitable for use as a basis for characterising emissions from incinerator facilities in Australia.

B.5 References

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