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020203 & 020204
020303 & 020304
030104 & 030105

SOURCE ACTIVITY TITLE: COMBUSTION IN ENERGY & TRANSFORMATION INDUSTRIES
Particulate emissions from gas turbines and internal combustion engines

NOSE CODE:
101.01
101.02

NFR CODE:
1 A 1 a,b,c
1 A 2 a-f
1 A 4 b,c,i

ISIC
3510

1   ACTIVITIES INCLUDED

This supplement covers emissions of particulate matter (PM) released from combustion processes within the energy and transformation industries by internal combustion engines - gas turbines and reciprocating engines . This supplement includes guidance on estimating total PM (TSP), PM_{10} and $PM_{2.5}$ emissions from these sources. Information related to the estimation of emissions of other pollutants from this sector is given in chapter B111.

2   CONTRIBUTION TO TOTAL EMISSION

The contributions of PM_{10} and $PM_{2.5}$ emissions from combustion plant to total emissions in countries according to the CORINAIR90 inventory are indicated in Table 2.1.

Table 2.1 Contribution to total particulate matter emissions from 2004 EMEP database (WEBDAB)

NFR Sector	Data	PM_{10}	$PM_{2.5}$	TSP
1 A 1 a - Public Electricity and Heat Production[a]	No. of countries reporting	26	26	27
	Lowest Value	0.2%	0.2%	0.2%
	Typical Contribution	11.7%	10.1%	12.8%
	Highest Value	48.8%	47.8%	48.4%
1 A 2 - Manufacturing Industries and Construction[b]	No. of countries reporting	26	26	26
	Lowest Value	0.7%	0.6%	0.6%
	Typical Contribution	9.0%	9.5%	7.9%
	Highest Value	20.7%	22.1%	25.7%
1 A 4 a - Commercial / Institutional[c]	No. of countries reporting	23	23	23
	Lowest Value	0.1%	0.1%	0.1%
	Typical Contribution	3.9%	3.4%	4.5%
	Highest Value	19.3%	22.2%	29.5%
1 A 4 b - Residential[d]	No. of countries reporting	3	2	3
	Lowest Value	2.0%	6.5%	3.7%
	Typical Contribution	14.9%	26.2%	10.8%
	Highest Value	36.6%	45.8%	15.4%
1 A 4 b i - Residential plants[e]	No. of countries reporting	23	23	23
	Lowest Value	2.7%	5.8%	0.8%
	Typical Contribution	28.3%	33.1%	22.0%
	Highest Value	67.1%	74.6%	53.2%
1 A 5 a - Other, Stationary (including Military)[f]	No. of countries reporting	7	7	7
	Lowest Value	0.0%	0.0%	0.0%
	Typical Contribution	0.1%	0.1%	0.1%
	Highest Value	0.5%	0.4%	0.6%

[a] Includes contribution from Chapter 112

[b] Includes contributions from Chapter 112 and 316 (SNAP 030106)

[c] Includes contribution from Chapter 112 and 216 (SNAP 020205)

[d] Includes contribution from Chapter 810

[e] Includes contribution from Chapter 112

[f] Includes contribution from Chapter 112 and 216 (SNAP 020106)

3   GENERAL

3.1   Description

This supplement considers emissions of PM generated by internal combustion engines including gas turbines and reciprocating engines. Reciprocating engines include compression ignition (CI) and spark ignition (SI) technologies. Other emissions from this source category are considered in B111.

3.2 Definitions

See B111.

3.3 Techniques

See B111 for more information on combustion plant types and fuels.

Gas turbines range in size from <100kW electrical generation (microturbines) to over 250 MW electrical generation. The most common primary fuel is natural gas but gas oil and a range of derived fuels are also used.

Diesel compression engines also range from a few kW to about 50 MW electrical generation. The most typical fuel is gas oil but, various derived fuels can be used and heavy fuel oil is used on some large units. Dual fuel engines burn natural gas or derived gases with a small quantity of gas oil.

3.4 Emissions

Internal combustion engines use liquid or gaseous fuels and particulate emissions result mainly from combustion of the fuels.

Combustion of liquid fuels can generate solid residues which may be deposited within exhaust ducts oron heat exchanger surfaces (soot and fly ash). Suspended ash material in exhaust gases may be retained by particulate abatement or other emission abatement equipment (abatement residues). Material which remains in the flue gases beyond the abatement equipment and passes to the atmosphere is primary PM. Secondary PM is formed by chemical and physical processes after discharge to atmosphere and is NOT considered here.

3.5 Controls

Particulate emission reduction is not usually associated with combustion of gaseous fuels except where derived fuels are used (in which case filtering or other treatment of the fuel gas is the preferred approach). Particulate abatement equipment may be used with oil fuels and can include, fuel pre-treatment to reduce mineral content (particularly for heavy fuel oil), diesel particle filters (on smaller units) or more traditional emission abatement equipment. . N.B. Emission concentrations of TSP from compression ignition engines associated with Best Available Techniques (BAT) as defined by EU Integrated Pollution Prevention and Control regulations are 30 mg m^{-3} for gas oil and 50 mg m^{-3} for heavy fuel oil.

4   SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

> Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.
>
> Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.
>
> Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the Tier 1 simpler methodology, where limited information is available, a default emission factor can be used together with activity information for the country or region of interest with limited or no specification on the type of technology or the type and efficiency of control equipment.   For a Tier 2 approach an approximation may be made of the most representative technologies, thereby allowing the use of more appropriate default factors if more detailed activity data are available.

Consequently the simplest methodology (Tier 1) is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = \text{AR x EF}$$

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

The Tier 2 methodology is a modified version of this basic equation:

$$\text{Emission} = \sum((AR_1 \text{ x } EF_1) + (AR_2 \text{ x } EF_2) + \ldots (AR_n \text{ x } EF_n))$$

Default emission factors for this purpose are provided in Sections 8.1 and 8.2.

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[1]   The term "Tier" is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

5   DETAILED METHODOLOGY

The detailed methodology (equivalent to Tier 3) to estimate emissions of pollutants from combustion plant >50 MW$_{th}$ is based on measurements or estimations using plant specific emission factors - guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

In many countries, operators of combustion plant >50MWth will report emissions to comply with regulatory requirements and this data can be used to help compile the national inventory.

The recommended detailed methodology to estimate emissions of PM from combustion activities is based on measurements and/or estimations using technology-specific emission factors.

Information on the type of the process and activity data, for example combustion and abatement technologies, is required to assign appropriate emission factors.

6   ACTIVITY STATISTICS

Activity statistics for energy consumption or other relevant national activity data for estimating emissions using the simpler estimation methodology (Tiers 1 and 2) are available from national statistics.

The detailed methodology (Tier 3) requires more detailed information such as the amount and types of fuel consumed within individual combustion plant or industry sectors. These data are not always easily available although in many countries operators do report fuel use for emission trading or other legislative requirements.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 2 on energy, Chapter 1.

7   POINT SOURCE CRITERIA

Large combustion plants are regarded as point sources if plant specific data are available.

8   EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1   Default Emission Factors For Use With Simpler Methodology (Tier 1)

Fuel	Technology	Emission factor, g.GJ^{-1}			Notes
		TSP	PM$_{10}$	PM$_{2.5}$	
Hard Coal		-	-	-	Not applicable
Brown Coal		-	-	-	Not applicable
Other solid fuels		-	-	-	Not applicable

Natural gas	Gas turbines	0.9	0.9	0.9	US EPA
	Spark ignition	18	18	18	US EPA 2 stroke lean burn, 4 stroke lean burn is 0.04 gGJ^{-1}.
Derived gases	Gas turbine	11	11	11	Based on US EPA Landfill gas
Heavy fuel oil	Diesel	28	23	22	US EPA factor for diesel engines
Other liquid fuels	Gas turbine	2.0	2.0	2.0	US EPA factor for PM applied to other fractions
	Diesel	28	23	22	US EPA
Biomass	Gas turbine	11	11	11	Landfill gas
	Gas turbine	5.7	5.7	5.7	Anaerobic digester gas

8.2   Reference Emission Factors For Use With Tier 2 Methodology

Tables 8.2a-z contain reference particulate emission factors for fuel combustion in various technologies with different types of abatement.

Table 8.2a   Emission factors for gas turbines combustion processes

Fuel	NAPFUE	NFR Codes	Activity description	Activity detail	Emission factor, g.GJ^{-1}			Notes
					TSP	PM$_{10}$	PM$_{2.5}$	
Natural gas					0.9	0.9	0.9	Sierra (234 tests), assumes all PM2.5
Gas oil					3	3	3	Sierra (15 tests), assume all PM2.5

Table 8.2b   Emission factors for compression ignition combustion processes

Fuel (IPCC Cat)	NAPFUE	NFR Code	Activity description	Activity detail	Emission factor g GJ^{-1}			Reference/Comments
					TSP	PM$_{10}$	PM$_{2.5}$	
Natural gas			Dual fuel engine, gas with HFO		11	11	11	LCP BREF, assumed all PM2.5
Heavy fuel oil			Diesel engine		50	41	39	LCP BREF, 'BAT' US EPA profile applied
			Diesel engine		<64	53	50	LCP BREF, US EPA profile applied, applicable to older equipment
Gas oil			Diesel engine	<0.02% S	<26	21	20	LCP BREF, US EPA profile
			Diesel engine		<17	14	14	Smaller unit with diesel particulate filter, US EPA profile

9   SPECIES PROFILES

The US EPA (2003) undertook a review of species profiles within $PM_{2.5}$ and reports particle size distribution data for a variety of fuels and combustion and abatement technologies. Some of these data are dated and have high uncertainty ratings. Profiles of other materials are not available.

Table

Profile ref	Profile name	Component				
		POA	PEC	GSO4	PNO3	Other
22002	Residual Oil Combustion	0.1075	0.0869	0.5504	0.0005	0.2547
22003	Distillate Oil Combustion	0.0384	0.0770	0.3217	0.0024	0.5605
22004	Natural Gas Combustion	0.6000	0.0000	0.2000	0.0055	0.1945

Notes:
POA - Primary organic aerosol derived from organic carbon
PEC Elemental Carbon
GSO4 - Sulphate
PNO3 - Nitrate
Other – Remainder of PM2.5 material emitted.

Note that the data are derived from a variety of sources including dilution tunnel measurements and may not be directly comparable with filterable $PM_{2.5}$.

10   UNCERTAINTY ESTIMATES

The overall 'Uncertainty' in national emission inventories may be significant – as illustrated in Table 9.1.

Table 9.1 Uncertainty estimate for selected pollutants in the UK air emission inventory (NAEI, 2005).

Pollutant	Estimated Uncertainty (%)
PM_{10}	-20 to +50
$PM_{2.5}$	-20 to +30
$PM_{1.0}$	-10 to +20
$PM_{0.1}$	+/- 10
Sulphur Dioxide	+/- 3
Oxides of Nitrogen	+/- 8
NMVOCs	+/- 10
Ammonia	+/- 20

There is uncertainty in both the aggregated emission factors and activity data used to estimate emissions i.e. the imprecision and error to be expected from the application of an 'average' emission factor or activity statistic to estimate emissions from a specific sector - an artificial grouping of 'similar' sources.

The uncertainty is partly the result of how emission factors are developed and applied.   In the case of primary particulate matter, the expanded statistical uncertainty is made up of: between plant variance, within plant variance, and uncertainties associated with the measurement methodology used and the aggregation of data. The measurement data in Annex 1 illustrates the variability in emission factors that occurs from between plant variance.

Process measurements, from which emission factors are developed at individual facility level, are subject to both systematic and random errors in the determination of mass concentration, mass emission, size distribution, and analytical errors etc.

In addition bias may exist in emission factors arising from:

1. Assumptions made about the abatement used on 'typical' industrial installations. For example emission factors 'age', the factors widely used in the Guidebook and hence by many countries as default emission factors in their national inventories become out of date. Recent measurement work suggests that they may overestimate emissions from the industrial processes subject to more modern industrial emissions regulation. They may, however, still be fully representative for older plant, small plant, or for poorer fuels;

Assumptions about the relationship between TSP and PM_{10}/$PM_{2.5}$. The technical literature is comprehensive for TSP and the data quality can be good if measurements have been made using the international standard methods that are available (typically the 95% confidence limit ~10%). But a variety of methods are used for particle size fractionation and as yet there are no harmonised international standards to ensure comparability. Published measurement data for PM10 is sparse, that for $PM_{2.5}$ emissions more so. An added complication is that the methodology for the determination of TSP differs from that of PM10 and $PM_{2.5}$ and so the two need not correlate directly.

11   WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Published $PM_{2.5}$ emission factor information for stationary engines is sparse. It is difficult to form a representative estimate the emissions likely to arise from the range of engine/fuel combinations commonly encountered. Further work is required to develop a more complete range of emission factors.

12   SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Combustion plants should be considered as point sources if plant specific data are available. Otherwise national emissions should be disaggregated on the basis of plant capacity, employment or population statistics.

13   TEMPORAL DISAGGREGATION CRITERIA

Combustion processes can be considered as a continuous process however individual combustion plant may have daily and/or seasonal temporal profiles.

14   ADDITIONAL COMMENTS

See chapter B111 and B111 (S2) for measurement data in Annex 1.

15   SUPPLEMENTARY DOCUMENTS

None

16   VERIFICATION PROCESSES

Published $PM_{2.5}$ emission data for stationary engines is sparse.

17   REFERENCES

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18   BIBLIOGRAPHY

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Source: R. Stewart
               AEA Technology
               The Gemini Building
               Didcot,
               OXON
               OX11 0QR

20   POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Robert Stewart

AEA Technology Environment
The Gemini Building
Didcot
OXON
OX11 0QR

Tel: +44 870190 6575
Fax: +44 870190 6318
Email: robert.stewart@aeat.co.uk

Jozef Pacyna

NILU - Norwegian Institute of Air Research
PO Box 100
N-2027 Kjeller
Norway

Tel: +47 63 89 8155
Fax: +47 63 89 80 50
Email: jozef.pacyna@nilu.no