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Determination of Atmospheric Pollutant Emission Factors at a Small Coal-fired heating boiler

A report produced for the Department of the Environment, Transport and the Regions, the National Assembly for Wales, the Scottish Executive and the Department of the Environment for Northern Ireland

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Executive Summary

AEA Technology has undertaken a programme of measurements at a bituminous coal-fired, underfeed stoker heating boiler to determine pollutant emission factors for the Department of Environment, Transport and the Regions (DETR), the National Assembly for Wales, the Scottish Executive and the Department of the Environment for Northern Ireland. The emission factor data are intended for further development of the UK National Atmospheric Emissions Inventory (NAEI) which is maintained by AEA Technology on behalf of DETR.

Emission measurements were undertaken at a heating boiler at an infant school. The SNAP code for the furnace is 020103. Emission factors were determined for the following determinands :

- Polychlorinated dibenzo-p-dioxins (PCDD)
- Polychlorinated dibenzofurans (PCDF)
- Polychlorinated biphenyls (PCB)
- Polycyclic aromatic hydrocarbons (PAH)
- Metals
- Total Particulate matter (TPM), PM_{10} , $PM_{2.5}$
- Carbon Monoxide (CO)
- Benzene

A summary of the emission factors determined in the programme is provided in the following table.

Pollutant	**Emission factor**	
	ng kg^{-1}	**ng MJ^{-1}**
Total PCDD/F (ITEQ)	51	1.8
Total PCB	1440	50.8
Total PCB (ITEQ)	1.5	0.053
	µg kg^{-1}	**µg MJ^{-1}**
Total PAH	1650	57.9
	mg kg^{-1}	**mg MJ^{-1}**
Total Metals	22.4	0.79
	g kg^{-1}	**g MJ^{-1}**
TPM	2.33	0.082
Benzene	<0.01	<0.0003
CO	9.96	0.350

Notes :
1. Factors are calculated for mass of coal **as burned** and for **net** thermal input.
2. See main text for speciated PCDD/F, PCB, PAH and metals emission factors.

This work indicates that the PAH data in the NAEI may overestimate emissions of several PAH compounds from coal combustion by several orders of magnitude. Incorporation of the data from this investigation into the NAEI may reduce some of the uncertainty associated with PAH emissions from this source category.

The PAH emission factors determined for this heating boiler indicate that the EMEP/Corinair PAH default emission factors and emission profiles may not be applicable to UK small coal-fired processes.

Naphthalene emission factors determined in this investigation are likely to underestimate emissions and consequently the emission factors determined in this investigation are not proposed for inclusion in the NAEI. In the absence of other data, a factor of 31,000 kg Mt^{-1} is proposed for Naphthalene.

It is recommended that the NAEI adopt the other PAH factors from this investigation. The data should be assessed by the NAEI to determine if emissions are significant and if further emission measurements are required to improve uncertainty for the source sector.

The determined dioxin emission concentrations are comparatively high and indicate that small coal combustion units could be a significant source of dioxins and furans emission.

In the absence of other data specific to UK processes and to provide a 'worst case' emission inventory it is recommended that the NAEI adopt dioxins emission factors from this investigation. The significance of the emission from the process sector should be assessed by the NAEI and the need for further investigation determined.

In the absence of other published data for PCB emissions from coal combustion at heating boilers, AEA Technology recommends inclusion of the emission factors determined in this investigation into the NAEI. The contribution of small coal-fired heating plant to UK PCB emissions should be assessed by NAEI to determine if further source monitoring is required.

No revision to the NAEI emission factor for CO is proposed. However, if CO emissions are significant from this sector, further investigation may be required to improve uncertainty for the sector.

Benzene measurements provided limited information and it is recommended that no change is made to the current NAEI factor. The NAEI should determine if benzene emissions are significant and if further investigation is required to improve uncertainty for the source sector.

No revision to the NAEI PM_{10} factor for coal combustion is proposed. However, it is proposed that the NAEI adopt an USEPA-based factor for $PM_{2.5}$. The factors should be assessed by the NAEI to determine if emissions are significant and if further investigation is required to improve uncertainty for the source sector.

The metals emission factors from this investigation are proposed for inclusion in the NAEI. However, the factors should be assessed by the NAEI to determine if emissions are significant and if further investigation is required to improve uncertainty for the source sector.

Contents

1 Introduction

AEA Technology has undertaken a programme of measurements at a small commercial bituminous coal-fired heating boiler to determine pollutant emission factors for the Department of Environment, Transport and the Regions (DETR), the National Assembly for Wales, the Scottish Executive and the Department of the Environment for Northern Ireland. The emission factor data are intended for development of the UK National Atmospheric Emissions Inventory (NAEI) which is maintained by AEA Technology on behalf of DETR.

This report summarises a work programme undertaken to determine emission factors for the following determinands:

- Polychlorinated dibenzo-p-dioxins (PCDD)
- Polychlorinated dibenzofurans (PCDF)
- Polychlorinated biphenyls (PCB)
- Polycyclic aromatic hydrocarbons (PAH)
- Metals
- PM_{10}
- $PM_{2.5}$
- Carbon Monoxide (CO)
- Total Particulate Matter (TPM)

The existing information on emission factors from coal-fired heating boilers in the NAEI for the above substances is either highly uncertain or absent altogether. This set of tests was required in order to allow the NAEI to assess the significance of small coal-fired heating boilers as a source of these substances.

The emission factors derived from the emission measurements are compared with emission factors currently used in the NAEI and emission factors published by the US Environmental Protection Agency (USEPA) and in the UNECE EMEP/Corinair Atmospheric emissions inventory guidebook.

2 Plant Description

Emissions to atmosphere were measured in the flue gases from a coal-fired heating boiler at an infant school. The boiler provides hot water for the heating system of the school. The boiler burns bituminous coal and has a capacity of about 500 kW. It has an underfeed stoker and has no abatement or combustion monitoring equipment.

The SNAP (Selected Nomenclature of Air Pollution) source code for the furnace is **020103**.

Selection of the process was based on several criteria. Ideally, the site chosen was to be representative of such installations. The plant selected was chosen following a survey of Education Authorities, which are the main operators of these units in the UK. Selection was based on the co-operation offered by operators, ease of access to the site, the availability of sampling facilities, a reasonably constant operation and the ease of installation of sampling equipment.

3 Emission factors

3.1 DEFINITION

An emission factor enables the calculation of the quantity of a pollutant discharged to atmosphere from a specified process with a known production activity, and has been defined[1] as, "a statistical average of the rate at which a pollutant is released to the atmosphere as a result of some activity such as combustion or industrial production divided by the rate of that activity".

3.2 DERIVATION

There are several ways of deriving (and expressing) emission factors. The method which has been used to derive the emission factors at combustion plant in this measurement programme is based on a knowledge of the fuel composition, via chemical analysis, and an analysis of the flue gas.

For combustion processes, the ultimate analysis of the fuel can be used to provide the theoretical (stoichiometric) flue gas volume and composition associated with a unit of the fuel (for example for a kg of coal). The relationship between the oxygen concentration and the excess air is then determined. The flue gas oxygen analysis is then used to calculate the total volume of flue gas (per unit of fuel). The mass of pollutant emitted per unit of fuel (the pollutant emission factor) can then be calculated from the flue gas analysis and the derived flue gas volume.

This approach has the advantage that it can be applied almost universally to combustion processes. Other techniques for measurement of emission factors require information that may not be readily available or cannot be accurately measured at all plant.

3.3 EXPRESSION

Emission factors for combustion sources are usually expressed as the mass of pollutant emitted divided by the mass or volume of fuel burned (for example, g CO per kg coal).

When comparing emission factors it is necessary to express the emission factors in comparable terms for example, g pollutant per kg dry, ash-free coal, g pollutant per m^3 gas at STP (0°C, 101.3 kPa), or per unit of heat input, g GJ^{-1} (on a Net or Inferior basis).

The emission factors for coal combustion in this report are expressed as a mass of pollutant per mass of coal as burned (for example g kg^{-1}), as a mass of pollutant per mass of dry, ash-free coal burned and, as a mass of pollutant per unit of net thermal input.

4 Experimental

4.1 SAMPLING POSITION

The sampling position is installed in a section of the ductwork, between the boiler and the stack. Ideally the selected sampling position should be located downstream of all abatement and sources of flow disturbances where the velocity profile is even across the duct and the flue gases are homogeneous. The sampling position should allow sampling methodologies to be conducted to recognised standards.

Most of the target pollutants have a significant particulate fraction and the sampling methodologies require multi-point isokinetic sampling on a grid pattern across two or more traverses (dioxins, furans, PCBs, PAHs, TPM, PM_{10}, $PM_{2.5}$). However, multi-point sampling could not be conducted in full accordance with the standard methods, as there was only a single access port fitted at the sampling position, due to access constraints about the duct.

Gas velocities within the stack were generally below the limit of detection of the measurement system which indicates that the sampling position was not suitable for sampling particulate material. However, no other locations were available at this process. It is likely that similar problems affect other installations of this type.

4.2 AIR EMISSIONS SAMPLING METHODS

The releases to air were monitored using AEA Technology documented procedures, shown in Table 1. Many of the procedures employed by AEA Technology are UKAS accredited however, deviations from the procedures were necessary for several measurements.

4.3 FUEL ANALYSIS METHODOLOGY

A fuel sample was obtained during the visit and submitted for ultimate analysis. Analysis of the fuel sample was undertaken by TES Bretby, P.O. Box 100, Burton-on-Trent, Staffordshire.

Table 1 – Source sampling methods

Determinand	AEAT WI	Source Document	Other Details	UKAS accreditation	
				Sampling	Analysis
Dioxins and furans	105	EN 1948	Multi-component sampling train. Min. 6hr isokinetic sampling. Triplicate sampling and analysis. HR GCMS analysis for 2,3,7,8 isomers.	Yes	Yes
PAHs	105	EN 1948	Multi-component sampling train. Min. 6hr isokinetic sampling. Triplicate sampling and analysis. HR GCMS analysis for 33 priority PAHs.	Applied	Yes
PCBs	105	EN 1948	Multi-component sampling train. Min. 6hr isokinetic sampling. Triplicate sampling and analysis. HR GCMS analysis for 23 priority congeners.	Applied	Yes
Benzene	113	NIOSH 1501	Sample for 1-60 mins @ 0.1 l. min^{-1} onto 2 x charcoal sorbent tubes in series. Triplicate sampling and analysis.	Yes	Applied
Carbon Monoxide	116	ISO12039	On-line tests using heated line, IR detection. Throughout all tests.	Yes	Yes
Carbon Dioxide	122	ISO 12039	On-line tests using heated line, IR detection. Throughout all tests.	Yes	Yes
Oxygen	117	ISO12039	On-line tests using heated line, paramagnetic detection. Throughout all tests.	Yes	Yes
Metals	133	USEPA 29	Isokinetic sampling of vapour and particulate phase metals. Minimum 1 hour test. Triplicate sampling and analysis. Analysis using ICP-MS and ICP-AES	Yes	Yes
PM_{10}	134	USEPA 201A	Gravimetric method, using multi-point sampling. Triplicate sampling and analysis. Min. 1 hr tests.	No	No
$PM_{2.5}$	(Based on 134)	(Based on USEPA 201A)	Gravimetric method, using multi-point sampling. Triplicate sampling and analysis. Min. 1 hr tests.	No	No
TPM	118	ISO 9096	Gravimetric method, using multi-point sampling. Triplicate sampling and analysis. Min. 1 hr tests.	Yes	Yes

5 Emission Factor Results

The determined emission factors are summarised in the Tables 2 to 6. Spreadsheet calculations used in the determination of these factors are included in Appendix A to D of this report. The concentrations in the tables have been standardised to reference conditions of 6 % O_2, dry and STP (273K, 101.3 kPa). The emission factors are given relative to the mass of coal as burned and for a dry, ash-free coal. The thermal emission factors are calculated using a net (inferior) calorific value of 28 MJ/kg for the coal as burned (see fuel analysis at Appendix E). Unless otherwise stated, the results are derived from the average of three similar tests for each determinand.

Table 2 - Dioxin and Furan Emission Factors

Determinand	**Average Emission Concentration**	**Emission factors**		
	ng (ITEQ)/m^3	**ng (ITEQ)/MJ**	**ng (ITEQ)/kg**	**ng (ITEQ)/kg (daf)**
2378 T4CDD	0.81	0.276	7.86	8.92
12378 P5CDD	1.32	0.450	12.80	14.53
123478 H6CDD	0.13	0.045	1.28	1.45
123678 H6CDD	0.13	0.045	1.28	1.45
123789 H6CDD	0.10	0.034	0.96	1.09
1234678 H7CDD	0.07	0.025	0.71	0.81
O8CDD	0.005	0.002	0.05	0.05
2378 T4CDF	0.32	0.109	3.09	3.51
12378 P5CDF	0.18	0.060	1.72	1.95
23478 P5CDF	1.60	0.544	15.45	17.54
123478 H6CDF	0.16	0.055	1.57	1.78
123678 H6CDF	0.19	0.066	1.86	2.12
123789 H6CDF	0.08	0.027	0.77	0.87
234678 H6CDF	0.09	0.031	0.88	1.00
1234678 H7CDF	0.02	0.008	0.22	0.25
1234789 H7CDF	0.01	0.002	0.06	0.07
O8CDF	0.0004	0.0001	0.004	0.005
Total	**5.22**	**1.8**	**51**	**57**

Table 3 - Polycyclic Aromatic Hydrocarbons (PAH) Emissions Factors

Determinand	Average Emission Concentration	Emission Factor		
	ug/m^3	ug/MJ	ug/kg	ug/kg (daf)
Naphthalene	109.02	37.119	1055.30	1198.12
Acenaphthylene	4.11	1.401	39.82	45.21
Acenaphthene	0.98	0.333	9.47	10.76
Fluorene	0.17	0.058	1.66	1.88
Phenanthrene	27.59	9.394	267.07	303.21
Anthracene	0.09	0.031	0.88	1.00
2-methyl phenanthrene	0.19	0.064	1.82	2.07
2-methyl anthracene	0.01	0.004	0.10	0.11
1-methyl anthracene	0.06	0.022	0.63	0.71
1-methyl phenanthrene	0.07	0.023	0.65	0.73
9-methyl anthracene	0.01	0.004	0.10	0.11
4,5-methylene phenanthrene	0.01	0.004	0.10	0.11
Fluoranthene	10.38	3.534	100.46	114.06
Pyrene	0.96	0.328	9.32	10.58
Retene	0.12	0.040	1.13	1.29
benzo(c)phenanthrene	0.63	0.214	6.08	6.91
Benzo(a)anthracene	0.79	0.271	7.69	8.74
Chrysene	3.21	1.093	31.08	35.28
Cyclopenta(c,d)pyrene	0.22	0.075	2.14	2.43
Benzo(b)naph (2,1-d) thiophene	0.35	0.118	3.36	3.81
5-methyl chrysene	0.01	0.004	0.10	0.11
Benzo(b)fluoranthene	3.65	1.244	35.38	40.17
Benzo(k)fluoranthene	2.48	0.845	24.01	27.26
Benzo(e)pyrene	1.46	0.497	14.13	16.05
Benzo(a)pyrene	0.23	0.079	2.25	2.56
Indeno(123cd)pyrene	1.81	0.617	17.53	19.91
Dibenzo(ah/ac)anthracene	0.38	0.130	3.71	4.21
Benzo(ghi)perylene	0.92	0.314	8.94	10.15
Anthanthrene	0.01	0.004	0.10	0.11
dibenzo(al)pyrene	0.01	0.004	0.10	0.11
dibenzo(ae)pyrene	0.17	0.056	1.60	1.82
dibenzo(ai)pyrene	0.01	0.004	0.10	0.11
dibenzo(ah)pyrene	0.01	0.004	0.10	0.11
Total	**170**	**57.9**	**1650**	**1870**

Table 4a - Polychlorinated Biphenyl (PCB) Emission Factors

PCB IUPAC No.	Average Emission Concentration		Thermal Emission Factor	
	ng/m^3	$ng(TEF)/m^3$	ng/MJ	ng(TEF)/MJ
18	12.1		4.13	
31	15.6		5.32	
28	12.3		4.19	
51	1.9		0.65	
52	13.8		4.70	
49	5.7		1.93	
47	6.8		2.32	
101	21.3		7.25	
99	2.5		0.84	
77	2.3	0.00023	0.79	0.00008
123	0.8	0.00008	0.27	0.00003
118	4.3	0.00043	1.47	0.00015
114	0.5	0.00026	0.18	0.00009
153	24.5		8.34	
105	0.5	0.00005	0.18	0.00002
138	16.1		5.49	
126	1.4	0.14160	0.48	0.04821
167	0.9	0.00001	0.30	0.00000
156	1.0	0.00050	0.34	0.00017
157	0.8	0.00040	0.27	0.00014
180	2.4	0.00002	0.81	0.00001
169	1.1	0.01103	0.38	0.00376
189	0.5	0.0001	0.18	0.00002
Total	**149**	**0.155**	**50.8**	**0.0527**

Table 4b – Polychlorinated Biphenyl (PCB) Emission Factors

PCB IUPAC	Emission Factor			
No	ng/kg	ng(TEF)/kg	ng/kg (daf)	ng(TEF)/kg (daf)
18	117.3		133.2	
31	151.3		171.8	
28	119.2		135.4	
51	18.5		21.0	
52	133.7		151.8	
49	54.9		62.3	
47	66.0		74.9	
101	206.2		234.1	
99	23.9		27.1	
77	22.4	0.00224	25.4	0.00254
123	7.7	0.00077	8.7	0.00087
118	41.7	0.00417	47.3	0.00473
114	5.0	0.00249	5.7	0.00283
153	237.2		269.3	
105	5.0	0.00050	5.7	0.00057
138	156.1		177.2	
126	13.7	1.37066	15.6	1.55615
167	8.4	0.00008	9.6	0.00010
156	9.8	0.00488	11.1	0.00554
157	7.7	0.00385	8.7	0.00437
180	22.9	0.00023	26.0	0.00026
169	10.7	0.10679	12.1	0.12124
189	5.0	0.00050	5.7	0.00057
Total	**1440**	**1.50**	**1640**	**1.70**

Table 5 – Particulate, Benzene and Carbon Monoxide Emission Factors

Determinand	Average Emission Concentration	Emission Factor		
	mg/m^3	g/MJ	g/kg	g/kg (daf)
Total Particulate Matter	241	0.082	2.33	2.65
PM_{10}	No data	-	-	-
$PM_{2.5}$	No data	-	-	-
Benzene	<0.8	<0.0003	<0.01	<0.01
Carbon Monoxide	1029	0.350	9.96	11.3

Note :

1. Data for PM_{10} and $PM_{2.5}$ have not been reported due to poor quality test data.

Table 6 – Summary of metals emission results

Determinand	Average Emission Concentration	Emission Factor		
	mg/m^3	mg/MJ	mg/kg	mg/kg (daf)
As	0.136	0.046	1.31	1.49
Cd	0.003	0.001	0.03	0.03
Co	0.032	0.011	0.31	0.35
Cr	0.016	0.006	0.16	0.18
Cu	0.563	0.192	5.45	6.18
Hg	0.046	0.016	0.45	0.51
Mn	0.146	0.050	1.42	1.61
Ni	0.109	0.037	1.05	1.19
Pb	0.492	0.167	4.76	5.40
Sb	0.047	0.016	0.46	0.52
Sn	0.014	0.005	0.14	0.16
Tl	0.010	0.003	0.09	0.10
V	0.057	0.020	0.56	0.63
Se	0.050	0.017	0.48	0.55
Zn	0.590	0.201	5.72	6.49
Total	**2.31**	**0.787**	**22.4**	**25.4**

6 Comparison with NAEI, USEPA and UNECE Emission Factors

6.1 COMPARISON WITH NAEI EMISSION FACTORS

Table 7 summarises the latest published (1998)[2] NAEI emission factors for miscellaneous, public service coal combustion and compares the data with the factor determined at the heating boiler.

Table 7 – Comparison with NAEI 1998 emission factors

Pollutants	**Emission factors,**	
	NAEI	**AEAT**
	Misc, Public service	**heating boiler**
	kg Mt^{-1}	
Acenaphthene	2622	9.47
Acenaphthylene	3578	39.82
Anthracene	925	0.88
Benzo[a]anthracene	894	7.69
Benzo[a]pyrene	775	2.25
Benzo[b]fluoranthene	35	35.38
Benzo[ghi]perylene	408	8.94
Benzo[k]fluoranthene	12	24.01
Chrysene	835	31.08
Dibenzo[ah]anthracene	896	3.71
Fluoranthene	1502	100.5
Fluorene	8105	1.66
Indeno[1,2,3-cd]pyrene	596	17.5
Naphthalene	61703	1055
Phenanthrene	3283	267
Pyrene	1491	9.32
	kt Mt^{-1}	
Benzene	0.00189	<0.01
CO	4.1	9.96
	g Mt^{-1}	**gITEQ Mt^{-1}**
Dioxins	2.4	51

Notes :
1. NAEI factors are from 'Miscellaneous, public service' category of fuel use.

The average CO and benzene emission factors determined at the heating boiler are higher than the NAEI factors although the benzene measurements are subject to high uncertainty as the measured concentrations were below the LOD. The PAH emission factors are generally lower than the current NAEI emission factors and for some components are several orders of magnitude lower. The emission factor determined in this investigation for Naphthalene is likely to underestimate emissions of this comparatively volatile PAH. The dioxin emission factor determined by AEA Technology is significantly higher than the current NAEI factor.

6.2 COMPARISON WITH EMEP/CORINAIR EMISSION FACTORS

Emission factors from the UNECE EMEP/Corinair atmospheric emission inventory guidebook[3] are compared with the emission factors determined in this investigation in Table 8.

The EMEP/Corinair PAH factors are for only four species and these are derived from Benzo(a)pyrene concentrations and PAH profiles for each emission source. The Benzo(a)pyrene and Indeno(123cd)pyrene emission factors determined at the coal furnace are much lower than the EMEP/Corinair factors, however the benzofluoranthene emission factors are similar. The PAH emission profile determined in this investigation differs from that published by EMEP/Corinair.

The determined CO emission factor is higher than the EMEP/Corinair factor for commercial boilers. It should be noted that CO emissions are very sensitive to operating conditions and this may not be representative of emissions from other units. The determined CO_2 emission factor (based on fuel analysis) is similar to the published CO_2 emission factors.

The EMEP/Corinair guidebook includes a method for the calculation of metals emissions from the fuel analysis. The metal content of the fuel was not determined during this investigation and the equation could not be tested. Emission factors are provided by the guidebook but only for coal combustion at larger boilers which would have particulate and other abatement equipment.

Table 8 - Comparison with EMEP/Corinair Atmospheric Emission Inventory Guidebook

Pollutant	**Emission factors, mg t^{-1}**	
	EMEP/Corinair	**AEAT**
Benzo(a)pyrene	1550 (775)	2.25
Benzo(b)fluoranthene	77.5 (38.8)	35.4
Benzo(k)fluoranthene	15.5 (7.75)	24.0
Indeno(123cd)pyrene	1240 (620)	17.5
	g GJ^{-1}	
CO	195	350
	kg GJ^{-1}	
CO_2	93.7, 92	90

Notes :

1. Main figures for EMEP/Corinair PAH emission factors are maximum figures assigned to small industrial coal combustion plant with no emission controls. The factors in parentheses represent default 'best estimates' for industrial coal combustion plant.
2. EMEP/Corinair factors for PAH compounds other than Benzo(a)pyrene are based on emission ratio profiles for industrial and domestic coal combustion.
3. The EMEP/Corinair CO emission factor is for a commercial boiler burning steam coal.

6.3 COMPARISON WITH USEPA EMISSION FACTORS

6.3.1 Overview

Table 9 compares the emission factors for the heating boiler with factors published by USEPA[4]. The USEPA has published a large number of factors for industrial coal combustion. Although a comparison of mass based emission factors has been prepared, the thermal emission factors provide a better means for comparing data from differing fuels. It should be noted that the thermal factors presented in Table 10 are calculated for the gross (superior) heat input.

The USEPA classifies coal combustion sources into several categories. The heating boiler is an uncontrolled underfeed stoker boiler (that is it has no emission control equipment). Although USEPA has published a wide range of default emission factors, most are for different categories of combustion plant.

6.3.2 Total Particulate and Carbon monoxide

The TPM emission factor is lower than the published USEPA factor however, the CO emission factor is higher than the USEPA default factor.

6.3.3 Metals

The USEPA has published a limited number of trace element emission factors from uncontrolled stoker boilers. The factors determined during this investigation are generally lower than the USEPA data.

Table 9 – Comparison with USEPA emission factors

Pollutant	Emission factors			
	kg t^{-1}		kg GJ^{-1}	
	USEPA	AEAT	USEPA	AEAT
PM	3.8	2.3	0.13	0.078
PM_{10}	3.1	No Data	0.10	No Data
$PM_{2.5}$	1.9	No Data	0.06	No Data
CO	5.5	10	0.18	0.34
	mg t^{-1}		mg GJ^{-1}	
Cr	246-3900	160	8.2-130	5.4
Mn	28,000	1420	933	48.1
Hg	207	450	6.9	15.3
Ni	9990-16,700	1050	333-555	35.6

Notes :

1. USEPA Emission factors are based on as-fired coal within a range of 10 700 to 14 700 BTU/lb. An assumed gross calorific value of 13 000 BTU/lb (30 MJ/kg) has been used to calculate USEPA thermal emission factors. The coal burnt at this plant had a moisture content of 9.2 % and gross calorific value of 29.5 MJ/kg.

Like EMEP/Corinair, USEPA does also provide formulae for calculation of selected metal emissions from fuel analysis and knowledge of the process (boiler type and abatement). The metal content of the fuel was not determined and hence it has not been possible to assess the appropriateness of the formulae published by USEPA to UK conditions.

7 Uncertainty of Emission Factors

The overall uncertainty of the emission factors have not been determined. Some guidance on the likely uncertainties is provided in the analytical uncertainties associated with measured concentrations (Appendices A to D). However, these uncertainties are limited as they do not include a provision for the deviations from the particulate sampling protocol, which affects almost all of the species measured. For example, the sampling of particulate material may have an uncertainty of up to 45%. The calculation of the emission factor introduces additional uncertainty from the sampling and analysis of the fuel.

The determined emission factors are based on a single heating boiler burning bituminous coal. The factors are considered to be representative of normal operation of the process tested and should be applicable to other similar UK heating boilers.

The dioxin and furan measurements showed a large variation (over an order of magnitude) over the three tests. However, the analysis results were well above the Limit of Detection (LOD) for the analysis technique employed. The variation may be typical of this type of process. The three tests gave a mean concentration of 5.2 ng(ITEQ).m^{-3}, with a relative standard deviation over the three tests of 96%.

The analysis results indicate that the pattern of PAH emissions is also variable, with the predominant species being naphthalene in each case. Other species such as phenanthrene, acenaphthylene, fluoranthene and chrysene were also found at levels well above their respective LODs in each test. Many of the species analysed for were found at levels that were very close to the LOD. The variability of figures across the three tests is greater than in the case of dioxins and furans, with a mean emission concentration of total PAHs of 170 $\mu g.m^{-3}$, with a relative standard deviation over the three tests of 86%.

The PCB analysis also showed variation between tests although the relative standard deviation was slightly lower (75%).

Benzene concentrations were below the LOD of the analysis method and consequently have a very high uncertainty.

The uncertainty of particulate measurements may be as high as 45 %.

8 Findings and Recommendations

8.1 PAH EMISSIONS

This work indicates that the PAH data in the NAEI (which is based on information published by EMEP/Corinair) may overestimate emissions of many components by several orders of magnitude. Incorporation of the data from this investigation may reduce some of the uncertainty associated with PAH emissions from this source category.

The PAH emission factors determined for this heating boiler indicate that the EMEP/Corinair PAH emission profile may not be applicable to UK coal combustion.

Naphthalene emission factors determined in this investigation are likely to underestimate emissions and consequently the emission factors determined in this investigation are not proposed for inclusion in the NAEI.

It is recommended that the NAEI adopts PAH factors from this investigation. In the absence of other data, a factor of 31,000 kg Mt^{-1} is proposed for naphthalene (an average of the current NAEI naphthalene factor and the factor determined in this investigation). The data should be assessed by the NAEI to determine if emissions are significant and if further emission measurements are required to improve uncertainty for the source sector.

8.2 DIOXINS AND FURANS EMISSION FACTORS

The determined emission concentrations are comparatively high (compared to emission limits for waste incineration) and indicate that small coal combustion units could be a significant source of dioxins and furans emission.

In the absence of other data specific to UK processes and to provide a 'worst case' emission inventory it is recommended that the NAEI adopt emission factors from this investigation. The significance of the emission from the process sector should be assessed by the NAEI and the need for further investigation determined.

8.3 PCB EMISSION FACTORS

In the absence of other published data for PCB emissions from combustion, AEA Technology recommends inclusion of the emission factors determined in this investigation into the NAEI. The contribution of small coal-fired heating plant to UK PCB emissions should be assessed by NAEI to determine if further source monitoring is required.

8.4 CARBON MONOXIDE AND BENZENE

The NAEI emission factor for CO for industrial coal combustion is lower than the emission factor determined at this plant but within an order of magnitude. Consequently, no revision to the NAEI factor is proposed. However, if CO emissions are significant from this sector, further investigation may be required to improve uncertainty for the sector.

Benzene measurements provided limited information and it is recommended that no change is made to the current NAEI factor. The NAEI should determine if benzene emissions are significant and if further investigation is required to improve uncertainty for the source sector.

8.5 METALS

The emission factors determined in this investigation are similar to USEPA default emission factors. The data are proposed for inclusion in the NAEI however, the factors should be assessed by the NAEI to determine if emissions are significant and if further investigation is required to improve uncertainty for the source sector.

8.6 PARTICULATE, PM_{10} AND $PM_{2.5}$

The NAEI does not currently estimate emissions of total particulate or $PM_{2.5}$. The PM_{10} and $PM_{2.5}$ emission measurements failed to provide useful information. However, the NAEI factor for PM_{10} (2.5 kt/Mt) is similar to the USEPA default emission factor for coal-fired underfeed stoker boilers (3.1 kt/Mt). It is proposed that the NAEI adopt a USEPA-based factor for $PM_{2.5}$ however the factors should be assessed by the NAEI to determine if emissions are significant and if further investigation is required to improve uncertainty for the source sector.

9 Acknowledgement

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Appendix A
Summary of test data – 21 November 2000

Appendix B
Summary of test data – 22 November 2000

Appendix C
Summary of test data – 23 November 2000

Appendix D
Summary of test data – 24 November 2000

Appendix E
Fuel Analysis

Fuel analysis

Table E1 – Summary of fuel analysis

Sample	Analysis, %	
	As Received	**Dry, Ash Free**
Moisture	9.20	-
Ash	2.70	-
Volatile Matter	34.80	39.50
Fixed Carbon	53.30	60.50
Carbon	69.60	79.00
Hydrogen	4.39	4.98
Nitrogen	1.70	1.93
Chlorine	0.52	0.59
Sulfur	1.23	1.40
CV (Gross)	29.5	33.5
CV (Net)	28.4	32.3