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TRACE ELEMENT CONCENTRATIONS IN SOME COAL SAMPLES AND POSSIBLE EMISSIONS FROM COAL COMBUSTION IN SWEDEN.

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SUMMARY

Coal samples from different mining districts were collected and analysed for trace element concentrations. These were As, Ba, Be, Br, Ca, Cd, Cl, Co, Cr, Cu, F, Fe, Hg, In, Mn, Mo, Na, Ni, Pb, S, Sb, Se, Sr, Ti, Tl, V and Zn. On the basis of the concentrations of these elements found in coal and on empirically measured emission factors, trace element emissions from a 1000 MW coal-fired power plant were estimated.

TRACE ELEMENTS IN SOME COAL SAMPLES AND POSSIBLE EMISSIONS FROM COAL COMBUSTION IN SWEDEN

BACKGROUND

Oil is today the predominant fossil fuel used for energy production in Sweden. However, because of the present energy resources situation, coal combustion is being considered for use as a possible alternative in the energy production.

Like other fossil fuels, coal is a heterogenous material containing trace amounts of nearly all naturally existing elements. At combustion these elements will be found in the bottom ash slag and in the flue gases. Although the concentrations of the elements in the fuel are generally low, the amount emitted may be considerable due to the large consumption of fuel. Even when high-efficient stack gas cleaning equipment is used, some emission of trace elements is inevitable.

Compared to oil, the concentrations of most elements in coal are high. Emissions from coal combustion may therefore be expected to increase the concentrations of heavy metals and other potentially harmful substances in the environment.

A literature survey concerning the current knowledge on trace element emissions from coal combustion was recently made (1).

In order to make an estimation of the possible emissions from a future Swedish coal-fired power plant, coal samples were collected and analysed. The coal samples came from different mining districts, from which coal in the future might be imported to Sweden.

As mentioned above, the composition of coal is complex, and the concentrations of both major and minor elements vary widely between coals from different mining districts and even between coals from the same pit. These variations are a result of differences in conditions during formation of the coal as well as to the influence of percolating water in the coal layers.

As a consequence, the coal concentrations reported here only represent a limited choice of coal samples and will merely give an indication of the levels of trace metal emissions from coal combustion.

COLLECTION AND ANALYSIS OF COAL SAMPLES

Coal samples from seven different countries (Norway, England, USA, West Germany, Poland, the Soviet Union and Australia) were collected through assistance by a Swedish coal import company, Rydberg & Streiffert AB. A list of the coals sampled, their origin and analytical data are given in Table 1.

For analysis of trace elements, particularly trace metals, many different methods are reported in the literature. Due to the complexity of coal and to the volatility of many elements, analysis is difficult. Two different methods often give two different results. The U.S. National Bureau of Standards have made up standard coal samples, to make possible a comparison of the different methods used. Results from inter-laboratory tests show that, generally, neutron activation is the superior method (2). This method does not require any sample pre-treatment, something which always involves risks of losses and of contamination. Neutron activation is also free from matrix effects.

Prior to analysis, the coal samples were pulverised by grinding. All the elements in this study except for Be, F, Pb, S and Tl were determined through neutron activation analysis. For Hg, Zn and Cd a radiochemical separation procedure was used.

Be, Pb and Tl were analysed with emission spectrography. For the analysis of F the coal samples were digested with sulphuric acid and distilled. F was determined as F^- with an ion-selective electrode. S was determined gravimetrically as $BaSO_4$ after digestion of the coal sample in a MgO-Na_2CO_3 melt.

RESULTS

The results of analysis are presented in Table 2. A comparison between these results and trace element concentrations in coal reported in the literature (3) is made in Table 3. Although the variations in trace metal concentration between the different coal samples are relatively large, the mean value of the twelve coals agrees remarkably well with reported mean values for most of the elements. For more than 10 of 25 elements, the Norwegian and the USA B coal samples show concentrations considerably lower than the mean concentrations obtained. In the English coal sample, six of the elements are present in concentrations considerably higher than the observed means while only one is considerably lower. For the Australian coal sample, the corresponding number of elements is eight and eight, respectively.

ESTIMATION OF POSSIBLE EMISSIONS FROM COAL COMBUSTION

The amount of trace elements emitted from a coal-fired power plant will depend mainly on the initial trace element concentrations in the coal, but also on combustion engineering and pollution control at the plant.

Different combustion processes will yield different primary emissions. In a cyclone-fed boiler more than half of the coal ash (about 60% at the T A Allen Plant (13)) is found as bottom ash and the rest as fly ash. In a pulverised coal-fired boiler only about 10-20 % is retained as bottom ash while about 80-90 % of the coal ash goes out with the flue gases as fly ash.

To be able to calculate the emissions it is necessary to know the fate of the trace elements during combustion. It has been shown that a partitioning of elements between slag and fly ash occurs. The process is not understood in detail but it is quite clear that elements (such as As, Cd, Hg, Pb, Sb, Se, Zn and halogenes),having low boiling points (below the normal combustion temperature, 1300-1600^{O}C), are volatilised in connection with combustion (10). Some of the elements (such as Hg, Se and halogenes) remain wholly or partially in the vapour phase in the stack gases. Other elements, shortly after combustion, adsorb or condense onto surrounding particles in the flue gases. As a result of this, the finer particles, having a larger surface area per mass unit than the coarser ones, will have higher concentrations of the volatile elements than the coarser particles. This enrichment process is of great importance for the emissions, since the finer particles are more difficult to remove from the stack gases with conventional particle precipitators.

The degree of volatilisation depends not only on the furnace temperature but also to some extent on the coal matrix. For example, for coals with a high concentration of Ca, more As will be retained as arsenite or arsenate in the ash than for a coal with a low Ca concentration (11).

Boulding (21) gives the following equation for calculating trace element emissions:

$$E_p = \frac{8.76 \cdot E_c \cdot K \cdot h_r \cdot I}{h_c} \cdot f$$

where

E_p = amount emitted (tons/year)

E_c = concentration of the element in coal ($\mu g/m^3$)

K = plant capacity (MW)

h_r = plant's heat rate (BTU/kWh)

I = plant load factor

h_c = heat content of the coal (BTU/ton)

f = emission factor = $\frac{\text{mass flow of the element emitted}}{\text{mass flow of the element with coal}}$

The emission factor (f) differs from element to element and also from plant to plant. It should therefore be determined empirically for each element by mass balance studies at each plant.

Emission factors (mass flow of the element emitted in % of the mass flow of the element with coal) obtained in mass balance measurements at the T A Allen Steam Plant (10, 19) and Valmont Power Station (11) are compiled in Table 4. T A Allen Steam Plant (13) is a modern 870 MW crushed coal-fired plant with three cyclone-fed boilers. The plant is equipped with high-efficient electrostatic precipitators, probably the best available technology for particle pollution abatement (27). Valmont Power Station (11) is a pulverized coal-fired boiler, with a special particle pollution abatement system. The flue gases are passed through a "high-efficient" mechanical dust collector. The gas stream is then split up. One part (about 40 %) goes to an electrostatic precipitator and the rest goes to a wet scrubber.

From Table 4 it will be seen that for the relatively volatile elements As, Cd, Pb and Zn the emission factors at the T A Allen Steam Plant are about 2 % and for the non-volatile elements around 0.50 % or less. For Sb and Se, 10-30 % are emitted, while 90-100 %

of the most volatile elements, Hg and the halogenes, are emitted mainly as vapour. It has been assumed that As, Sb, Se and perhaps also Cd, Pb, and Zn may exist to some extent in the vapour phase. Only Se has been detected, however (10). About 10-15 % of the Se in coal will be emitted as vapour and about 1 % will be particle-borne (12).

At the pulverised coal-fired Valmont Power Station, the emission factors are considerably higher. However, results are available for only six elements.

Trace element emissions were calculated for the most favourable case among those presented in Table 4 by using the coal concentrations in Table 2.

Table 5 shows the emission estimates for a 1000 MW cyclone-fed plant with high-efficient (99.5 %) electrostatic precipitation, made on the basis of the emission factors obtained at the T A Allen Steam Plant (10) (see Table 4, column 2). The coal consumption per hour is estimated at 365 tons. The emission factor for Hg is assumed to be 90% and for F 100% (Table 4). The emissions of Be, Cu, In, Mo, Ni and Sr are not estimated since no corresponding emission factors are available for these elements.

DISCUSSION

The trace element emissions from coal combustion given in Table 5 are calculated for a power plant with extremely good particle pollution abatement equipment and are probably hard to reduce further with conventional abatement techniques and without special pre-treatment of the coal (22, 23). However, a wet scrubber for sulphur dioxide removal in addition to the electrostatic precipitator will probably decrease the emissions of some of the trace elements, at least the emissions of halogenes. The emissions of elements such as F, Hg, Sb and Se from a 1000 MW coal-fired plant are considerable and of the same order of magnitude as those from some industrial processes.

A comparision of relative emissions from coal and oil combustion based on the heat content of the fuel (g/kWh) is made in Table 6. Emissions from oil combustion are calculated from trace element concentrations in fuel oil 220"RI (No 3) (24,25), on the assumption that the total amount of trace elements in oil is emitted to the atmosphere.

For 13 elements comparable data are available. For seven of these (As, Cr, Fe, Hg, Mn, Sb and Se), the emissions per kWh from coal combustion seem to be larger than those from oil combustion. For four of the elements (Br, Cl, Co and V) the emissions per kWh from oil combustion seem to be larger. For Pb and Zn, there is no difference in emissions between the two types of combustion.

The environmental impact of emissions from coal combustion is of course not only related to the quantity emitted but also to the chemical and physical state of the emitted elements. Fly ash from coal combustion consists largely of relatively insoluble aluminium silicate glass particles. The major part of the elements contained in these particles is therefore not easily available for reactions in the environment. It appears, however, as if elements on the surface layer of particles would be quite readily soluble (8). This is of importance when considering that some of the elements enriched on the particle surfaces are toxic.

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REFERENCES

(1) Lövblad & Grennfelt: Tungmetaller och andra spårämnen i stenkol samt emissioner till luft av dessa ämnen vid kolförbränning - En litteraturstudie. IVL Rapport B 345, Göteborg(1977).

(2) Ondov et al.: Elemental Concentrations in the National Bureau of Standards' Environmental Coal and Fly Ash Standard Reference Materials. Analytical Chemistry 47 (7), 1102-1109 (1977.

(3) Bertine & Goldberg: Fossil Fuel Combustion and the Major Sedimentary Cycle. Science 173, 233-235 (1971).

(4) Ruch et al.: Occurrence and Distribution of Potentially Volatile Trace Elements in Coal. In interim report. Illinois State Geol. Surv. Environ. Geol. Notes (61), (1973).

(5) Lyon et al.: Analytical Chemistry Division, Annual Progress Report. For Period Ending September 30, 1972 ORNL-4838, Oak Ridge National Laboratory (1973).

(6) Bethell: The Distribution and Origin of Minor Elements in Coal. The British Coal Utilization Research Association Monthly Bulletin 26(12), 401-430 (1962).

(7) Crossley: Fluorine in coal III. The Manner of Occcurrence of Fluorine in Coal. Journal of the Society of Chemical Industry 63, 284-288 (1944).

(8) Natusch: Working Paper on Physical and Chemical Characteristics of Atmospheric Emissions from Fossil Fueled Power Plants. Seminar at the Swedish Environment Protection Board, 7 March, 1977.

(9) R F Weston Inc.: Environmental Impact Report. Coal Transshipment Facility Superior, Wisconsin. (July, 1974).

(10) Klein et al.: Pathways of Thirty-seven Trace Elements Through Coal-Fired Power Plant. Environmental Science & Technology 9 (10), 973-979 (1975).

(11) Kaakinen & Jordan: Trace Element Behaviour in Coal-Fired Power Plant. Environmental Science & Technology 9 (9), 862-869 (1975).

(12) Andren et al.: Selenium in Coal-Fired Steam Plant Emissions. Environmental Science & Technology 9 (9), 856-858 (1975).

(13) Bolton et al.: Trace Element Measurements at the Coal-Fired Allen Steam Plant. Progress Report June 1971 - January 1973 ORNL-NSF-EP-43. Oak Ridge National Laboratory (1973).

(14) Klein et al.: Trace Element Discharges from Coal Combustion for Power Production. Water, Air and Soil Pollution 5, 71-77 (1975).

(15) Billings & Matson: Mercury Emissions from Coal Combustion. Science 176, 1232-1233 (1972).

(16) Billings et al.: Mercury Balance in a Large Pulverized Coal-Fired Furnace. Journal of the Air Pollution Control Association 23 (9), 773-777 (1973).

(17) Fancher: Trace Element Emissions from the Combustion of Fossil Fuels, in: Cycling Contr. Metals. Proc. Environ. Resour. Conf. 1972, Ed. Curry, M.G., 109-113 (1973).

(18) Kalb: Total Mercury Mass Balance of a Coal-Fired Power Plant in: Trace Elements in Fuel. ACS Series 141, Ed. Babu, S.P. American Chemical Society, Washington D.C. 1975, 154-174.

(19) Bolton et al.: Trace Element Mass Balance Around a Coal-Fired Steam Plant. Ibid. 175-187.

(20) Crossley: Fluorine in Coal IV. The Industrial Significance of Fluorine in Coal, in Steam Raising, Gas Making and Brewing. Journal of the Society of Chemical Industry 63, 342-347 (1944).

(21) Boulding: What is pure coal?. Environment 18 (1), 12-36 (1976).

(22) Schutz et al.: The Fate of Some Trace Elements during Coal Pretreatment and Combustion, in: Trace Elements in Fuel. ACS Series 141, Ed. Babu,S.P. American Chemical Society, Washington D.C. (1975) 139-153.

(23) Capes et al.: Rejection of Some Trace Elements During Beinfication by Agglomeration. Environmental Science & Technology 8 (1) 35-38(1973).

(24) Andersson & Grennfelt: Determination of heavy metals in fuel oils and an estimation of the emissions of heavy metals from oil combustion. IVL Report B 138, Gothenburg (1973).

(25) Andersson & Grennfelt: The concentration of some trace elements in fuel oils and an estimation of the atmospheric emissions of these elements from oil combustion in Sweden. IVL Report B 204, Gothenburg (1974).

Table 1.

COLLECTED COAL SAMPLES.

Origin of the coals:			Ash (%)	Volatile compounds (%)	Sulphur[5] (%)	Heat of combustion (kWh/kg)
Norway		Spetsbergen	7	39	0,78	8,4
England			9	30	1,12	7,4
USA	A	Massey	-[4]	35[3]	1,02	8,1[3]
USA	B	Massey	-[4]	32[3]	0,61	8,6[3]
West Germany	HA	Ruhr	5[1]	28[2]	0,85	9,7[2]
West Germany	W		11[1]	35[2]	0,79	9,4[2]
Poland	A		-[4]	-[4]	0,60	~7,1
Poland	B		-[4]	-[4]	0,76	~7,1
Sovjet Union	A	Petchora	15-17[1]	34-35[2]	0,70	7,8-8,0[1]
Sovjet Union	B	Petchora	15	36[2]	0,50	9,4[2]
Sovjet Union	C	Kuznetsk	12	28[2]	0,40	9,3[2]
Australia		50 % Lithgow 50 % Katoomba (New South Wales)	15[3]	27[3]	0,47	7,3[3]

1) On dry coal basis

2) On dry ash free basis

3) "as received"

4) No data available

5) According to our analysis, on dry coal basis

Table 2.

RESULTS OF ANALYSIS OF COAL SAMPLES IN µg/g (EXCEPT FOR S)

	Norway	England	U S A		West. Germany		Poland		Sovjet Union			Austr.
			A	B	HA	W	A	B	A	B	C	
As	2,0	14,9	6,3	0,8	2,9	0,7	1,9	0,7	1,6	3,1	1,2	2,5
Ba	337	122	92	76	96	106	148	173	290	155	254	329
Be	<5	<5	<5	13	<5	<5	<5	<5	<5	<5	<5	15
Br	<2	99	23	12	16	8	13	10	14	5	5	<2
Ca	2200	1500	1500	500	1000	2100	4000	5400	5200	2800	450	240
Cd	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	0,1	<0,1	<0,1	<0,1	0,3
Cl	30	3680	1580	680	490	800	1200	1300	1230	150	30	80
Co	0,6	6,5	2,7	13,2	5,0	6,5	3,0	4,1	4,1	6,6	3,5	18,4
Cr	1,8	12,5	11,4	3,9	10,3	15,4	6,5	8,6	7,7	17,4	7,7	6,5
Cu	<5	22	14	15	12	21	14	13	24	8	6	15
F	54	75	39	17	45	42	72	32	58	53	83	64
Fe	6200	6100	9100	1370	6600	2300	9000	9600	6000	26200	14500	2000
Hg	0,066	0,120	0,066	<0,015	0,124	0,115	0,050	0,070	0,177	0,111	0,074	<0,015
In	0,009	0,028	0,013	<0,005	0,019	0,028	<0,005	0,020	0,023	0,022	0,021	0,074

(Table 2)

	Norway	England	U S A		West. Germany		Poland		Sovjet Union			Austr.
			A	B	HA	W	A	B	A	B	C	
Mn	<10	47	16	<10	224	24	127	134	151	36	77	21
Mo	0,26	2,68	0,70	0,99	1,69	1,49	0,61	0,39	1,31	1,51	1,01	2,23
Na	1340	1820	240	410	310	550	970	950	1160	860	340	60
Ni	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Pb	<10	<10	<10	<10	<10	<10	<10	14	<10	<10	<10	60
S	0,78%	1,12%	1,02%	0,61%	0,85%	0,79%	0,60%	0,76%	0,70%	0,50%	0,40%	0,47%
Sb	0,02	1,54	0,28	0,08	1,47	0,92	0,78	0,82	0,97	0,47	0,14	2,47
Se	1,5	1,4	3,7	1,8	1,0	1,8	0,9	1,8	1,5	1,2	0,6	<0,5
Sr	286	15	60	87	57	56	50	37	163	128	105	180
Ti	140	810	800	<100	< 200	360	340	350	920	1050	610	1120
Tl	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
V	5,5	39,5	16,6	5,8	23,8	34,0	8,7	14,5	24,2	26,3	12,7	20,5
Zn	0,3	15,1	3,1	1,1	9,6	13,3	24,4	34,0	16,7	23,7	17,3	116

Table 3.

COMPARISON BETWEEN RESULTS OF ANALYSIS AND TRACE METAL CONCENTRATIONS REPORTED IN THE LITTERATURE (1).

Element	Results of analysis (μg/g) Range	Results of analysis (μg/g) Mean	Reported Concentrations (μg/g) Range	Reported Concentrations (μg/g) Mean	Ref.
As	0,7 - 14,9	3,2		5	(3)
Ba	76 - 337	180		500	(3)
Be	<5 - ~15	<5		3	(3)
Br	<2 - 99	17	2 - 15	-	(4) (5)
Ca	240 - 5400	2240		10000	(3)
Cd	<0,1 - 0,3	<0,1	0,02 - 28	-	(4) (6)
Cl	30 - 3680	940		1000	(3)
Co	0,6 - 18,4	6,2		5	(3)
Cr	1,8 - 17,4	9,1		10	(3)
Cu	< 5 - 24	14		15	(3)
F	17 - 83	53	0 - 175	80	(7) (6)
Fe	2000 - 26200	8200		10000	(3)
Hg	<0,015 - 0,177	0,08		0,012	(3)
In	<0,005 - 0,074	0,022		-	
Mn	<10 - 224	72		50	(3)
Mo	0,26 - 2,68	1,2		5	(3)
Na	60 - 1820	760		2000	(3)
Ni	<50	<50		15	(3)
Pb	<10 - 60	6 - 15		25	(3)
Sb	0,02 - 2,47	0,83	<0,6 - 1,6	-	(4) (5)
Se	<0,5 - 3,7	1,5		3	(3)
Sr	15 - 286	100		500	(3)
Ti	<100 - 1120	560		500	(3)
Tl	<20	<20	{ 1-1000 0.1-0.2	-	(8) (9)
V	5,5 - 39,5	19		25	(3)
Zn	0,3 - 116	23		50	(3)

Table 4.

"EMISSION FACTORS" FOR TRACE ELEMENTS OBTAINED IN MASS BALANCE STUDIES AT COAL-FIRED STEAM PLANTS.

Massflow of element emitted in percent (%) of the mass flow of the element with coal. Allan Steam Plant: Cyclone-fed boiler, High efficient electrostatic precipitation. 1000 MW(e): Coal consumption 365 tons/hour. Valmont Power Station: Pulverized coal-fired boiler. Mechanical dust collector followed by electrostatic precipitator and wet scrubber in parallel. 1000 MW(e): Coal consumption 465 tons/hour.

	Allen Steam Plant (10) Prec.efficiency 96,5%	99,5%	Allen Steam Plant (19) (Two diff. methods of analysis)	Valmont Power Station (11) Total fly ash removal efficiency ~ 95%	Other rep.	Calculated USA mean values (14) [1)]
As	3,8	3,1	0,64 2,1			1,7
Ba		0,31	0,15			0,57
Be						
Br	~100					92
Ca	0,38	0,16	0,20 0,32			0,40
Cd	1,7	2,9	2,2			2,8
Cl	~97					97
Co	0,81	0,47	0,89 2,7			0,62
Cr		1,2	0,22 2,3			1,0
Cu			1,3	7,9		
F					~100(20)	
Fe	1,0	0,38	2,9 0,76	4,6		0,39
Hg	—(60-)90—				97(16) 97(15) 80(18) 85-95(8)	89
In						
Mn	1,2	0,40	1,5 0,77			0,51
Mo			0,16	15,7		
Na	0,95	0,39	1,1			0,41
Ni			⩾1,5			
Pb	2,2	2,8	>0,8			3,5

	Allen Steam Plant (10) Prec.efficiency		Allen Steam Plant (19) (Two diff. methods of analysis)		Valmont Power Station (11) Total fly ash removal efficiency	Other rep.	Calculated[1)] USA mean values (14)
	96,5%	99,5%			∼ 95%		
Sb		27					2,1
Se		12,5	35	5,3	12,6	13,6(12)	14,2
Sr					5,0		
Ti	0,88	0,54	0,23	0,56			0,62
Tl							
V	1 7	0,95	0,46	0,54			0,90
Zn	1,7	2,9		1,5	12,7		1,8

1) Calculated as a mean for USA (13 % of the coal burned in cyclone-fed boilers and stokers, 87 % burned as pulverized coal. High-efficient (99,5 %) electrostatic precipitation. Element partitioning between slag and flyash in accordance with TA Allen Steam Plant measurements).

ESTIMATED EMISSIONS OF TRACE ELEMENTS AT A 1000 MW(e) CYCLONE-FED POWER PLANT IN g/h. <u>Table 5.</u>

1000 MW(e) cyclone-fed boilers, high-efficient electrostatic precipitator (99,5 % total efficiency)
Coal consumption ∿365 ton/h.
Emissions factors from mass balance studies at T A Allen Steam Plant (10).

	Norway	England	USA A	USA B	Ger.HA	Ger.W	Pol.A	Pol.B	Sovj.A	Sovj.B	Sovj.C	Austr.
As	23	170	72	9,0	33	8,2	22	8,2	19	36	14	29
Ba	380	140	100	84	110	120	170	200	330	180	280	370
Br	<730	$36 \cdot 10^3$	$8,4 \cdot 10^3$	$4,4 \cdot 10^3$	$5,8 \cdot 10^3$	$2,9 \cdot 10^3$	$4,7 \cdot 10^3$	$3,7 \cdot 10^3$	$5,1 \cdot 10^3$	$1,8 \cdot 10^3$	$1,8 \cdot 10^3$	<730
Ca	1300	880	880	303	590	1200	2400	3200	3100	1600	260	140
Cd	<1,0	<1,0	<1,0	<1,0	<1,0	<1,0	<1,0	1,0	<1,0	<1,0	<1,0	3,2
Cl	$0,11 \cdot 10^5$	$13 \cdot 10^5$	$5,5 \cdot 10^5$	$2,6 \cdot 10^5$	$1,8 \cdot 10^5$	$2,9 \cdot 10^5$	$4,4 \cdot 10^5$	$4,7 \cdot 10^5$	$4,4 \cdot 10^5$	$0,53 \cdot 10^5$	$0,11 \cdot 10^5$	$0,28 \cdot 10^5$
Co	1,0	11	4,5	23	8,5	11	5,2	7,0	7,0	11	5,9	31
Cr	15	110	98	33	84	130	55	70	64	150	64	55
[illegible]	$20 \cdot 10^3$	$27 \cdot 10^3$	$14 \cdot 10^3$	$6,2 \cdot 10^3$	$16 \cdot 10^3$	$15 \cdot 10^3$	$26 \cdot 10^3$	$12 \cdot 10^3$	$21 \cdot 10^3$	$19 \cdot 10^3$	$30 \cdot 10^3$	$23 \cdot 10^3$
e	$8,6 \cdot 10^3$	$8,4 \cdot 10^3$	$12 \cdot 10^3$	$2,0 \cdot 10^3$	$9,2 \cdot 10^3$	$3,1 \cdot 10^3$	$12 \cdot 10^3$	$13 \cdot 10^3$	$8,1 \cdot 10^3$	$37 \cdot 10^3$	$20 \cdot 10^3$	$2,8 \cdot 10^3$
g	22	40	22	<5,1	40	37	16	23	58	37	24	<5,1

	Norway	England	USA A	USA B	Ger.HA	Ger.W	Pol. A	Pol. B	Sovj.A	Sovj.B	Sovj.C	Austr.
Mn	<15	69	24	<15	320	35	180	200	230	53	110	29
Na	$2,0\cdot10^3$	$2,6\cdot10^3$	360	585	460	780	$1,4\cdot10^3$	$1,4\cdot10^3$	$1,7\cdot10^3$	$3,8\cdot10^3$	$1,2\cdot10^3$	85
Pb	<102	<102	<102	<102	<102	<102	<102	140	<102	<102	<102	610
Sb	1,8	150	28	8,0	150	91	77	80	95	47	14	240
Se	71	64	170	86	46	86	39	86	71	56	<23	27
Ti	280	1600	1600	<200	<390	740	670	670	1800	2100	1200	2200
V	20	140	56	21	84	120	31	50	84	95	45	73
Zn	3,2	160	33	12	100	140	260	360	170	250	190	1200

Table 6.

COMPARISON OF EMISSIONS FROM COAL AND OIL COMBUSTION BASED ON THE HEAT VALUE OF THE RESPECTIVE FUEL.

COAL:
Trace element concentrations: Mean values of the 12 coal samples
% emitted at combustion: See table 4, column 2
Heat value: ∿8 kWh/kg coal

OIL:
Trace element concentration: Mean values 9 fuel oils (220"R1)(24)(25)
% emitted at combustion: 100 %
Heat value: ∿11 kWh/kg oil.

	Coal $g/kWh \cdot 10^6$	Oil $g/kWh \cdot 10^6$
As	13	6,4
Br	2,2	10
Cd	<0,3	<0,9
Cl	120	1200
Co	3,6	33
Cr	27	2,7
Fe	3800	400
Hg	9,3	0,20
Mn	38	6,4
Pb	52	65
Sb	28	0,26
Se	24	9
V	23	5700
Zn	83	83