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EMISSIONS ASSESSMENT OF CONVENTIONAL STATIONARY COMBUSTION SYSTEMS:
VOLUME IV. ~~COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES~~

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ABSTRACT

This report characterizes air emissions from commercial/institutional external combustion sources and reciprocating engines and is the fourth of a series of five project reports characterizing emissions from conventional combustion sources. The emissions characterization of commercial/institutional combustion sources was based on a critical examination of existing data, followed by a modified Level I sampling and analysis approach to resolve data gaps. The major deviation from Level I procedures was the addition of GC/MS analysis for polycylic organic matter (POM). Tests were conducted at 22 external combustion and six internal combustion sites.

The results of the environmental assessment indicate that air emissions from these sources represent a potential environmental hazard. Emissions of criteria pollutant, with the exception of carbon monoxide, from most of the source categories tested are environmentally significant. Particulate sulfate and SO_3 emissions from the coal- and wood-fired sources are also significant. In addition, emissions of several trace elements are of concern: aluminum, barium, beryllium, calcium, chlorine, cobalt, chromium, copper, fluorine, iron, potassium, lithium, sodium, nickel, phosphorus, lead, silicon, and vanadium from coal-fired external combustion sources; nickel from distillate oil sources; and nickel, chlorine, chromium, and vanadium from residual oil sources. Several potentially hazardous POM compounds were tentatively identified in the emissions from solid fuel-fired sources, particularly from the one wood-fired stoker tested. Flue gas emissions of POM from solid fuel-fired sources will require further study to positively identify the POM compounds emitted.

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1.0 SUMMARY AND CONCLUSIONS

Emissions from commercial/institutional external combustion sources for space heating and commercial/institutional internal combustion reciprocating engines are characterized in this report. The approach involves a critical review of existing emissions data, followed by the conduct of a sampling and analysis program to fill gaps in the data base and to identify additional data needs. Specifically, the objectives of this program were:

- to compile and evaluate available air emissions data from commercial/institutional stationary conventional combustion processes,
- to acquire needed new emissions data from field tests of selected sources using modified Level I procedures,
- to characterize air emissions from commercial/institutional stationary conventional combustion processes, using both the existing data base and field test results, and
- to determine additional data needs, including identification of specific areas of data uncertainty.

Level I procedures[1] use semiquantitative (plus or minus a factor of 3) techniques of sample collection and laboratory and field analysis: (1) to provide preliminary emissions data for waste streams and pollutants not adequately characterized, (2) to identify potential problem areas, and (3) to prioritize waste streams and pollutants in those streams for further, more quantitative testing. Using the information from Level I, available resources can be directed toward Level II testing which involves specific quantitative analysis of components of those streams that do contain significant pollutant levels. The data developed at Level II are used to identify control technology needs and to further define the environmental hazards associated with emissions.

1.1 COMMERCIAL/INSTITUTIONAL SOURCE DESCRIPTION

The commercial/institutional external combustion sources evaluated in this report are sources used for space heating of trade establishments, health and educational institutions, and government facilities. These application areas are identical to those used by the Department of Energy (DOE) in compiling energy consumption data for the commercial sector.[2] Commercial combustion units have also been defined as units with heat inputs ranging from 0.42 to 13.2 x 10^9 Joules (J)* per hour.[3,4] However, this definition excludes many smaller and larger units used in the commercial/institutional sector. Institutional units especially tend to be appreciably larger than 13.2 x 10^9 J/hr and account for almost 20 percent of the commercial/institutional sector fuel consumption.[5]

Commercial/institutional fuel consumption for space heating was 5.1 x 10^{18} J in 1978 based on DOE data for total fuel consumption[2] and estimates of the fraction of this fuel used for space heating.[6] This consumption value is less than 10 percent of the estimated 1978 national fuel consumption figure of 54 x 10^{18} J, excluding fuel used in the transportation sector.[2] Commercial/institutional external combustion sources for space heating primarily use oil (52 percent) and gas (44 percent). Small amounts of coal and wood are also used by the commercial/institutional sector. Internal combustion sources in the commercial/institutional sector, primarily gas- and oil-fired reciprocating engines, are used for pumping municipal water and sewage. Small amounts of fuel may also be used by internal combustion sources for auxiliary power generation.

Heating systems for commercial/institutional sources are concentrated in areas of high population density such as the Northeast, Midwest, and parts of California. Oil consumption is most heavily concentrated in the Northeast with the States of New York, Massachusetts, New Jersey, and Pennsylvania consuming about 25 percent of the U.S. total. Commercial gas consumption for space heating is more widely distributed than oil, but is still most heavily concentrated in the Midwest and Northeast.[7]

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*1055 Joules (J) = 1 Btu. Although it is EPA policy to use the metric system, this report uses certain nonmetric units for convenience. A conversion table is presented in Appendix D.

Commercial/institutional external combustion sources can be sold as either packaged units or boilers to be constructed onsite. Most units in the commercial sector are packaged units. Field-erected units, for the most part, are restricted to larger institutional facilities. Estimates of the total number of commercial external combustion sources have been reported[3,8] and, according to these estimates, there are approximately 1.5×10^6 commercial sources. Most of the smaller units ($< 13.2 \times 10^9$ J/hr) are cast iron or firetube units, and only 5 percent of these smaller units are of watertube design. Watertube units, however, constitute 100 percent of all units above 50×10^9 J/hr input.[8]

Air pollution control equipment is generally not installed on the smaller commercial external combustion sources, although new burner designs, atomization methods and furnace constructions are being studied to reduce emissions of NO_X and particulates. Burner modulation during periods of fluctuating demand, instead of on/off cycling, also reduces particulate and hydrocarbon emissions from oil-fired sources.[4]

1.2 EXISTING EMISSIONS DATA BASE

Gaseous and particulate emissions from the flue gas stacks are emphasized in this study of commercial/institutional combustion sources. Although some of the larger institutional external combustion systems are local sources of water pollution and fugitive particulate emissions from coal pile storage and ash disposal, their contribution to the national water pollution and fugitive emission burden is negligible. It is estimated, based on the amount of coal consumed by the commercial/institutional sector, that they contribute less than 1 percent of such emissions from all stationary combustion sources.

Evaluation of existing emissions data has indicated that the data base for gas- and oil-fired external combustion sources, although limited, is adequate for nitrogen oxides (NO_X), total hydrocarbon (HC), carbon monoxide (CO), particulate and sulfur dioxide (SO_2). However, the existing data base for specific organic emissions for these sources is inadequate, and, for the oil-fired sources, the existing data base for sulfur trioxide (SO_3) and trace elements is inadequate. Emissions data from solid fuel-fired sources are generally inadequate for all pollutants.

In the case of oil-fired internal combustion sources, data are inadequate for SO_3, trace element, and specific organic emissions. Data for gas-fired reciprocating engines are adequate; however, one unit was tested in this program to confirm data adequacy.

1.3 SOURCE MEASUREMENT PROGRAM

Modified Level I sampling and analysis procedures were used in this emissions assessment of conventional combustion systems program. These procedures were developed as an integral part of the program and were published as a separate document.[9] Although the procedures differ to some degree from official EPA Level I procedures, they have been used throughout this program to ensure continuity of sampling and analysis.

Because of the deficiencies in the existing emissions data base, the following 22 external combustion systems were tested: five gas-fired, three distillate oil-fired, five residual oil-fired, three anthracite stokers, three bituminous stokers, two bituminous pulverized dry units, and one wood-fired stoker. Four oil-fired, one gas-fired, and one dual-fired internal combustion reciprocating engines were also tested. Specific sites were chosen based on the representativeness of the sites as determined by the important system characteristics within each source category, including system design, size, and age. Many of the sites tested fall within the commercial size classification range, although some, particularly the pulverized bituminous-fired units, greatly exceed the upper commercial size limit of 13.2×10^9 J/hr input capacity.

1.3.1 Level I Field Testing

The Source Assessment Sampling System (SASS) train, developed under contract to EPA, was used to collect both gaseous and particulate emissions in quantities sufficient for the wide range of analyses needed to adequately characterize emissions from commercial/institutional combustion sources. The SASS train consists of a conventional heated probe, three cyclones and a filter mounted in a heated oven, a gas conditioning system, an XAD-2 polymer adsorbent trap, and a series of impingers. Particulate matter is size fractionated and collected in the cyclones and on the filter; gaseous organics and some inorganics are collected by the XAD-2 adsorbent; and the remaining gaseous inorganics and trace elements are captured by the impingers. The train is run until at least 30 m^3 of gas have been collected. This criterion was established in conjunction with analytical technique sensitivities to ensure that any emission that would increase the ambient loading by more than 1 $\mu g/m^3$ would be detected. The cyclones were deleted for the tests at the gas- and oil-fired sites because particulate loadings were too low to provide a weighable quantity of sample from each cyclone.

In addition to the SASS train, other equipment was used to collect gaseous components not captured by the train. A gas chromatograph (GC) with a flame ionization detector was used in the field to analyze C_1-C_6 hydrocarbons collected in gas sampling bags. Additionally, these samples were analyzed for CO, carbon dioxide (CO_2), oxygen (O_2) and nitrogen (N_2) by the GC using a thermal conductivity detector. Field sampling for NO_X and SO_3 was also conducted at selected sites using a Method 7 train for NO_X (40 CFR 60, Appendix A, Method 7) and a modified Goksöyr-Ross train[9] for SO_3 collection.

1.3.2 Modified Level I Laboratory Analysis

A modified Level I sampling and analytical procedure was used in this emissions assessment program. Major deviations from Level I Procedures were the addition of gas chromatography/mass spectroscopy (GC/MS) to the organic analyses, the combination of certain SASS train fractions before analysis, and the deletion of inorganic analysis of SASS train samples collected from gas- and oil-fired sources. The combination and deletion guidelines were instituted as a result of low levels of pollutants found in the emissions of previously tested gas- and oil-fired utility boilers and residential heating systems. Full details of the procedures used are presented in Section 4.

1.3.2.1 Inorganic Analysis

The Level I inorganic analysis was designed to identify all elemental species collected in the SASS train fractions and to provide semiquantitative data on the elemental distributions and total emission factors. The primary tool for Level I inorganic analysis is the Spark Source Mass Spectrograph (SSMS). SSMS data were supplemented with Atomic Absorption Spectrometry (AAS) data for mercury (Hg), arsenic (As), and antimony (Sb), and with standard method determinations for sulfates.

The following SASS train fractions from the solid fuel-fired sources were analyzed for their elemental composition: (1) the cyclone catches, (2) the particulate filter, (3) the XAD-2 sorbent, and (4) a composite sample containing portions of the XAD-2 module condensate and nitric acid rinse, and the first impinger solution. Fuel was also analyzed for the solid fuel- and oil-fired sources.

1.3.2.2 Organic Analysis

Level I organic analysis provides data on volatile (C_7-C_{16}) and nonvolatile ($> C_{16}$) organic compounds to supplement data for gaseous organics (C_1-C_6) measured in the field. Organics in the particulate fractions, the XAD-2 sorbent, and XAD-2 module condensate trap were recovered by methylene chloride extraction. SASS train components including the tubing were carefully rinsed with methylene chloride or methylene chloride/acetone solvent to recover all organics collected in the SASS train. SASS train rinses and extracts recovered from the gas- and oil-fired sites were combined for analysis; however, samples collected from solid fuel-fired sources were analyzed separately.

Because all samples contain significant quantities of solvents from rinsing and are too dilute to detect organic compounds by most instrumental techniques used by Level I procedures, the first step in the analysis was to concentrate the sample fractions from as much as 100 ml to 10 ml in a Kuderna-Danish apparatus in which rinse solvent was evaporated while the organics of interest were retained.* Kuderna-Danish concentrates were then evaluated by GC, gravimetric analysis, infrared spectrometry (IR), and sequential GC/MS.† The extent of the organic analysis was determined by the stack gas concentrations found for total organics (volatile and nonvolatile). If the total organics indicated a stack gas concentration below 500 $\mu g/m^3$, further analysis was not conducted. If the concentration was above 500 $\mu g/m^3$, a class fractionation by liquid chromatography was conducted followed by GC, gravimetric, and IR analyses. Fractions that contained more than the equivalent of 500 $\mu g/m^3$ or were of special interest were also analyzed by low resolution mass spectroscopy (LRMS).

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*Kuderna-Danish is a glass apparatus for evaporating bulk amounts of solvents.

†The major modification in the Level I sampling and analysis procedure was the GC/MS analysis for polycyclic organic matter (POM).

1.3.3 Results

The results of the field measurement program for flue gas emissions from commercial/institutional sources, along with supplementary values obtained from the existing data base for certain pollutants, are presented in Table 1. Also listed in this table are ambient severity factors, defined as the ratio of the calculated maximum ground level concentration of the pollutant species to the level at which a potential environmental hazard exists. An ambient severity factor of greater than 0.05 indicates a potential problem requiring further attention. See Appendix A for the rationale used to select 0.05 as the value indicative of a potential environmental problem.

The emission factors shown in Table 1 are uncontrolled emission factors. However, in the case of the solid fuel-fired combustion categories, some degree of particulate control does exist in the commercial/institutional sector. Overall particulate control efficiency is estimated to be 40 percent for bituminous, pulverized dry bottom boilers and 20 percent for all stokers. Gas- and oil-fired units are essentially uncontrolled. Control measures for other criteria pollutants are not used by commercial/institutional combustion sources.

As can be seen from Table 1, the criteria pollutants of concern are particulates from all uncontrolled solid fuel-fired combustion sources, NO_x from all source categories with the exception of wood-fired stokers, SO_2 from residual oil- and coal-fired sources, and HC from bituminous- and wood-fired stokers and internal combustion reciprocating engines. Ambient severity factors are all greater than 0.05 for these pollutant/source combinations. Emissions of CO from all combustion source categories do not appear to represent an environmental problem. Emissions of particulate sulfate and SO_3 from the solid fuel-fired combustion sources tested do appear to represent a problem since ambient severity factors exceed 0.05.

The trace element data shown in Table 1 indicate that many trace elements emitted by uncontrolled fossil fuel-fired combustion sources are of concern. Chlorine emissions, although not shown in the table, should also be of concern for residual oil and coal burning sources based on the chlorine content of these fuels. Ambient severity factors are generally greatest for bituminous, pulverized dry bottom boilers because of the larger capacity of these units.

TABLE 1. SUMMARY OF EMISSIONS CHARACTERIZATION OF COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES

Pollutant[a]	Combustion source category: Gas-fired boilers		Distillate oil-fired boilers		Residual oil-fired boilers		Bituminous, pulverized dry bottom		Bituminous stokers[b]		Anthracite stokers		Wood stokers		Gas-fired reciprocating engines		Oil-fired reciprocating engines	
	Emission factor (ng/J)	Ambient severity factor[c]	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor
Particulates	2	0.0007	6	0.0022	37	0.014	3,406	2.6	1,075	0.43	[illegible]	0.05	215	0.08	5	0.001	40	0.01
NO_x	50	0.08	68	0.11	172	0.28	352	1.2	117	0.19	[illegible]	0.24	10	0.017	1,390	1.66	1,420	1.7
SO_2	0.26	<0.0001	106	0.028	464	0.12	766	0.42	766	0.2	[illegible]	0.08	65	0.017	0.26	0.0001	97	0.017
CO	8	<0.0001	8	<0.0001	8	<0.0001	20	0.0002	195	0.0008	15	<0.0001	100	0.0004	300	0.0009	400	0.001
HC	3	0.0026	3	0.0026	3	0.0026	6	0.01	59	0.05	5	0.004	100	0.09	400	0.25	300	0.18
Particulate sulfated[d]	-	-	-	-	0.03	0.001	2.1	0.12	3.5	0.10	27.2	0.78	3.5	0.10	-	-	-	-
SO_3	-	-	-	-	-	-	1.0	0.07	12.2	0.44	19.3	0.07	-	-	-	-	-	-
Trace elements																		
Al	-	-	0.015	<0.0001	0.156	0.009	27.5	0.323	8.7	0.048	29.5	0.163	0.031	<0.001	-	-	0.288	0.001
Ba	-	-	0.0084	0.0005	0.0095	0.0006	4.24	0.517	1.33	0.077	0.278	0.016	0.010	<0.001	-	-	0.011	<0.001
Be	-	-	0.00004	0.0005	0.00007	0.0009	0.132	4.026	0.04	0.62	0.005	0.072	-	-	-	-	-	-
Ca	-	-	0.845	0.0056	0.780	0.0050	40.7	0.497	12.8	0.074	0.872	0.005	0.627	0.004	-	-	0.107	<0.001
Cc	-	-	0.0023	0.0013	0.023	0.0133	0.430	0.534	0.14	0.079	0.028	0.016	0.001	<0.001	-	-	0.0005	<0.001
Cr	-	-	0.036	0.0104	0.050	0.0144	0.825	0.563	0.26	0.084	0.376	0.109	0.004	0.002	-	-	0.006	0.001
Cu	-	-	0.205	0.0059	0.093	0.0028	0.605	0.037	0.19	0.006	0.175	0.005	0.004	<0.001	-	-	0.174	0.004
F	-	-	0.014	<0.0001	0.085	0.0003	3.245	0.079	1.02	0.012	0.270	0.003	0.015	<0.001	-	-	-	-
Fe	-	-	0.545	0.0032	0.379	0.0022	16.5	0.201	5.21	0.030	6.00	0.034	0.205	0.001	-	-	0.110	<0.001
K	-	-	0.060	0.0009	0.213	0.0031	10.5	0.320	3.31	0.048	2.856	0.041	1.48	0.021	-	-	0.144	0.001
Li	-	-	0.0015	0.0020	0.001	0.0013	1.155	3.203	0.36	0.477	0.079	0.104	0.001	0.001	-	-	0.0003	<0.001
Na	-	-	0.101	<0.0001	0.418	0.0022	20.35	0.248	0.42	0.036	0.825	0.005	0.024	<0.001	-	-	0.091	<0.001
Ni	-	-	0.112	0.0324	0.804	0.236	1.045	0.637	0.33	0.095	0.355	0.102	0.004	0.001	-	-	0.020	0.004
P	-	-	0.0057	0.0002	0.107	0.0031	4.675	2.852	1.48	0.425	2.11	0.578	0.137	0.039	-	-	0.016	0.003
Si	-	-	0.173	0.0005	1.610	0.0047	78.0	0.476	24.6	0.071	33.8	0.098	1.03	0.003	-	-	0.945	0.002
V	-	-	0.030	0.0002	3.66	2.05	1.375	0.167	0.43	0.025	0.170	0.010	0.0002	<0.001	-	-	0.004	<0.001
Total POM	0.010	-	0.020	-	0.044	-	0.002	-	0.5	-	0.003	-	26	-	-	-	0.430	-

- = No data.

[a] Uncontrolled emissions.

[b] Emission factors for criteria pollutants adjusted to reflect a capacity weighted distribution of stoker types.

[c] Ambient severity factor is defined as the ratio of the calculated maximum ground level concentration of the pollutant species to the level at which a potential environmental hazard exists. A value greater than 0.05 indicates a potential problem.

[d] Determined turbimetrically following hot water extraction of sulfate from the collected particulate.

However, ambient severity factors exceed 0.05 for many trace elements emitted by the smaller stoker-fired units. Elements of greatest concern appear to be aluminum, barium, beryllium, chromium, lithium, nickel, phosphorus and silicon. In addition, emissions of nickel from distillate oil sources, and nickel, chromium, and vanadium from residual oil sources are significant. Ambient severity factors based on the upper limit emission factor exceed 0.05. Information found in the existing data base would also indicate that ambient severity factors can exceed 0.05 for chlorine, cobalt, and magnesium emissions from residual oil combustion. Because many commercial/institutional fossil fuel-fired sources are totally uncontrolled or only partially controlled, further consideration of trace element emissions from these sources appears warranted.

POM emissions from some of the commercial/institutional sources tested are of significance. Of most concern were POM emissions from an underfeed stoker unit burning wood fuel during one test and bituminous coal during a second test. POM emission factors were extremely high for these tests, 15,000 and 26,000 pg/J, respectively, for coal and wood combustion. In addition, at least one active carcinogen, dibenz(a,h)anthracene, was identified, and the presence of other carcinogens; e.g., benzo(a)pyrene and benzo(g,h,i)-perylene, was indicated. Level II analysis is needed to provide positive identification of the POM compounds emitted by this stoker. It should be noted that this unit was operated at low heat input levels during both test periods. This operating condition would result in lower furnace temperatures and probably inefficient combustion, factors that would favor formation of POM compounds. Emissions of POM compounds from all other external combustion sources were not significant; levels were low (0 to 50 pg/J) and the compounds identified were primarily naphthalene and its derivatives.

POM emissions from the oil-fired (and dual-fired) reciprocating engines were relatively high, in the range of 100 to 800 pg/J. However, these emission levels were similar to those found in the existing data base for oil-fired engines, and ambient severity factors did not exceed 0.05 for any of the compounds detected. The high POM emissions measured for the dual-fired engine were somewhat surprising because the quantity of oil used represented only 5 percent of the total thermal input. No POM emissions were detected from the engine fired solely by gas.

1.4 CONCLUSIONS

Several conclusions, listed below, can be drawn from this emissions assessment of commercial/institutional combustion sources:

- Emissions of particulate, NO_x, SO_2, CO, and HC from commercial/institutional sources represent approximately 1.7 percent, 4.9 percent, 3.0 percent, 0.5 percent and 0.3 percent, respectively, of total emissions from stationary combustion sources. Despite this relatively minor contribution to national emissions, criteria pollutant emissions from individual combustion sources can have a significant local impact as noted below.

- Flue gas emissions of NO_x from all of the commercial/institutional source categories studied in this program, with the exception of a wood-fired stoker tested at low load conditions, are of concern. Ambient severity factors exceed 0.05 and, thus, individual sources can have a significant local impact.

- Flue gas emissions of SO_2 from the coal- and residual oil-fired combustion sources are associated with ambient severity factors greater than 0.05 and, thus, are of environmental significance. Ambient severity factors associated with particulate sulfate and SO_3 emissions from the solid fuel-fired sources tested also exceed 0.05 and are of concern.

- Flue gas emissions of particulates from uncontrolled solid fuel-fired sources are associated with high ambient severity factors. Moderate-to-high efficiency control devices are required in many cases to reduce severity factors to 0.05. Because the application of particulate control devices to solid fuel-fired commercial/institutional combustion sources is not extensive, these sources are of practical concern.

- Flue gas emissions of total hydrocarbon are significant for commercial/institutional bituminous stokers, wood stokers, and reciprocating engines. Ambient severity factors exceed 0.05 for these combustion source categories.

- Flue gas emissions of CO do not appear to be a problem. Ambient severity factors for all source categories are 0.001 or less.

- Particle size distribution data for particulate emissions from solid fuel-fired sources are inadequate. Data collected in this study exhibit large variability and contribute little to the limited information contained in the existing particle size distribution data base.

- Trace element emissions from uncontrolled coal-fired combustion sources are of concern. Elements with ambient severity factors in excess of 0.05 include aluminum, barium, beryllium, calcium, chlorine, cobalt, chromium, copper, fluorine, iron, potassium, lithium, sodium, nickel, phosphorus, lead, silicon and vanadium. Emissions of other elements also could be of significance given the variability of the elemental content of coals.

- Nickel emissions from distillate oil combustion sources, and nickel, chlorine, chromium and vanadium emissions from residual oil combustion sources are of concern. Ambient severity factors for these elements exceed 0.05.

- Flue gas emission data for POM compounds from gas- and oil-fired commercial/institutional sites appear to be adequate. Emission levels are generally low and the compounds that were detected have relatively high MATE values. Ambient severity factors for the compounds detected are all below 0.05.

- Flue gas emission data for POM compounds from solid fuel-fired combustion sources are still inadequate. Level II techniques should be used to study emissions from small coal- and wood-fired combustion sources. The effect of heat input levels, on/off operating modes, excess air levels, and other operating parameters on POM emissions should be studied in more detail. If these factors are found to contribute significantly to POM emissions, studies to determine the prevalence of contributory source operating parameters in the commercial/institutional sector should be undertaken to establish the magnitude of the problem.

2.0 INTRODUCTION

The combustion of common fuels--coal, oil, gas, and wood--in conventional stationary systems for heating and power generation is one of the largest and most widespread sources of environmental pollution affecting air, water, and land. In a preliminary assessment of the significance of stationary combustion systems as sources of pollution,[5] it was estimated that these combustion sources contribute a major portion of the total manmade emissions of NO_x, SO_2, and particulate matter. Furthermore, many of the combustion processes and associated pollution control technologies also produce solid wastes, in the form of ash and sludge, that present disposal problems. Leaching of chemical compounds and heavy metals from solid fuel or waste material, as well as direct discharges of wastewater streams, may result in contamination of water resources. Assessment of the environmental impacts is complicated by cross-media and multimedia effects as pollutants merge with or pass between environmental media. For example, removal of SO_2 and particulate matter from flue gases significantly increases the amount of solid wastes requiring disposal.

The U.S. Environmental Protection Agency (EPA) has long been active in regulating the release of pollutants from stationary conventional combustion processes. This involvement has included characterization of emission streams, research on the health and ecological effects of combustion pollutants, development and demonstration of pollution control technologies, and setting and enforcing environmental standards. Much of the earlier work on combustion pollutant characterization, however, has focused on the three major air pollutants--SO_2, NO_x, and particulate matter--and the subsequent development of control technologies and standards for these pollutants. As a consequence, the early characterization work was limited in scope and did not adequately address the emissions of other potentially hazardous pollutants or the multimedia aspects of combustion emissions. These observations were confirmed in the preliminary assessment study,[5] which identified the inadequate characterization of flue gas emissions of trace elements, sulfates, particulate matter by size fraction, and POM. In addition, the same study also identified the general inadequacy of the data base characterizating air emissions from cooling towers and coal storage piles, and wastewater effluents and solid wastes from combustion processes.

From the above discussion it is apparent that much of the data describing pollutant types and quantities released from stationary conventional combustion processes were unavailable. A comprehensive characterization of emissions from these processes, therefore, was needed as a basis for identifying the pollutants of concern, for estimating the total quantities of pollutants emitted, for assessing the impacts of pollutant emissions on health and the environment, and for evaluating the need for control technology development. In response to the need for a comprehensive characterization, the EPA's Industrial Environmental Research Laboratory at Research Triangle Park (IERL-RTP) in North Carolina established the Emissions Assessment of Conventional Combustion Systems program as one of the primary efforts for filling the identified data gaps. Specifically, the objectives of this program were:

- to compile and evaluate all available emissions data on pollutants from selected stationary conventional combustion processes,
- to acquire needed new emissions data from field tests,
- to characterize air emissions, wastewater effluents, and solid wastes generated from selected stationary conventional combustion processes, using combined data from existing sources and field tests, and
- to determine additional data needs, including specific areas of data uncertainty.

Because of the comprehensive characterization requirement, the assessment process in the current program is based on a critical examination of existing data, followed by a phased sampling approach to fill data gaps. In the first phase, sampling and analysis procedures are used to provide results accurate to a factor of 3 so that preliminary assessments can be made and problem areas identified. The methodology used is similar to the Level I sampling and analysis procedures developed under the direction of

EPA's IERL. The major addition is that GC/MS is used to analyze for POM in the samples collected in this program. Evaluation of results from the first phase will determine all waste stream/pollutant combinations requiring a more detailed and accurate Level II sampling and analysis program. In terms of major potential benefits, the characterization of combustion source emissions from this program will allow EPA to determine the environmental acceptability of combustion waste streams and pollutants and the need for control of environmentally unacceptable pollutants.

The combustion source types to be assessed in this program have been selected because of their relevance to emissions and because they are among the largest, potentially largest, or most numerous (in use) of existing combustion source types. A total of 51 source types have been selected for study. Selected source types have been classified under the following principal categories:

(1) electricity generation - external combustion,
(2) industrial - external combustion,
(3) electricity generation and industrial - internal combustion,
(4) commerical/institutional - space heating and internal combustion, and
(5) residential - space heating.

These five principal categories have been further divided into subcategories based on fuel type, furnace design, and firing method. The subcategories are needed because of the differences in the emission characteristics of combustion source types.

This program report is the fourth in a series of five source category reports and is concerned with characterizing emissions from commercial/institutional combustion sources. The main purposes of this report are to discuss data evaluation and test results and to provide, in a single document, best estimates of emission factors for stack gas effluents from commercial/institutional combustion sources. These emission estimates were derived using combined data from existing information sources and field tests conducted in the current program. The report also provides estimates of nationwide flue gas emissions from commercial/institutional combustion sources and identifies major gaps in emissions data. Information contained in the report can be used to:

- compile emission factors for pollutants for which no existing data were available,
- upgrade existing emission factors for pollutants,
- perform environmental assessments of commercial/institutional combustion sources,
- determine the nationwide burden of emissions from commercial/institutional combustion sources,
- evaluate the need for control technology development, based on analysis of the environmental impacts of uncontrolled and controlled emissions,
- plan future Level II field tests to provide critical data needs, and
- provide input to the development of emission standards.

Nine commercial/institutional combustion source types are considered:*

- 3.1.11.1.0 external combustion, bituminous, pulverized dry; ✓
- 3.1.11.4.0 external combustion, bituminous, stoker; ✓
- 3.1.12.4.0 external combustion, [redacted] ~~stoker~~; ✓
- 3.1.42.4.0 external combustion, wood, stoker; ✓
- 3.1.21.0.2 external combustion, residual oil, other; ✓
- 3.1.22.0.2 external combustion, distillate oil, other; ✓
- 3.1.30.0.2 external combustion, gas, other;
- 3.4.22.0.0 internal combustion, oil-fired reciprocating engine, and
- 3.4.30.0.0 internal combustion, gas-fired reciprocating engine.

The approach used in this emissions characterization of commercial/institutional combustion sources is similar to that used to characterize other source types. First, available information concerning the process and population characteristics of the combustion sources and their emissions was assembled and assessed to determine the adequacy of the available data base.

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*The numerical coding refers to the classifications used in Reference 5.

Sampling and analysis were then conducted at selected representative sites to fill identified data gaps in the existing data base. The results were evaluated to determine the need for and type of additional sampling and analysis and to identify the environmentally significant substances emitted from commercial/ institutional combustion sources. Emissions data obtained from the sampling and analysis program were combined with existing emissions data to provide estimates of current and future nationwide emissions of pollutants from commercial/institutional combustion sources. In Appendix A, the criteria for evaluating the adequacy of emission data are described. The data reduction procedure is presented in Appendix B.

3.0 SOURCE DESCRIPTION

The commercial/institutional sector consists of all conventional combustion activities not classified as electric utility, mining, manufacturing, transportation, or residential. It includes wholesale and retail trade, office buildings, hotels, restaurants, hospitals, schools, museums and government facilities.[10] Commercial combustion units generally range in size between 0.42 to 13.2×10^9 J/hr input capacity, whereas some commercial and many institutional units can be appreciably larger ($> 100 \times 10^9$ J/hr). The biggest units are found at large hospitals, office complexes, and government facilities such as military bases. The commercial/institutional use sector consumes less fuel than the residential, industrial, or electric utility sectors, thus, commercial/institutional sources are not major contributors to national emissions. Nevertheless, their environmental impact may be significant because of their high seasonal fuel consumption, their relative abundance and proximity to population centers, their almost total lack of pollution control equipment, and their release of emissions relatively close to ground level. To provide a better understanding of the emission problems associated with commercial/institutional combustion sources, brief descriptions of industry size and geographic distribution, combustion system design and fuel characteristics, number and size distribution of combustion units, fuel consumption, emission characteristics, and trends are provided in this section. Fuel use by source category and combustion system size are the principal factors used to aid in the selection of representative test facilities.

3.1 SIZE OF INDUSTRY AND GEOGRAPHIC DISTRIBUTION

Eighty-three percent of the total fuel consumed by the commercial/institutional sector during 1972 was used for space heating. Essentially all the coal and oil was used for space heating, whereas only 66 percent of the natural gas was used for space heating.[10] More recent data from DOE indicate that 75 percent of all gas and 86 percent of all oil burned by the commercial/institutional sector is for space heating.[6] The DOE data were used in this report to estimate fuel consumption for space heating.

Table 2 summarizes estimates of total fuel consumption by the commercial/institutional sector for the period 1974 through 1978. Residential sector consumption is also listed for comparison. There has been little change in the relative amounts of total fuel used by the residential and commercial sectors over the 5-year period, the former exceeding the latter by a factor of 1.5 in 1978. Total fuel consumption for the residential sector increased by about 5 percent, whereas commercial fuel consumption increased by nearly 4 percent. Trends are discernible in the choice of fuels. Natural gas increased by 6 percent while petroleum fell 1 percent. Coal's contribution to the total commercial/institutional sector fuel demand is only about 3 percent with petroleum and natural gas contributing about 52 and 44 percent, respectively. Percentage fuel consumption for national regions is shown in Table 3. In addition to showing the greater fuel consumption in colder and more highly populated regions, this table also shows the relatively high use of coal and gas in the central regions and the heavy reliance of the nation's Northeast on petroleum. Table 4 gives commercial/institutional petroleum consumption data for those states that are the heaviest users. The distribution of commercial/institutional fuel use in 1978 with respect to (1) external/internal combustion, (2) fuel type, and (3) fuel feed system is presented in Table 5. Fuel consumption projections for 1985 predict a modest increase in the use of coal, a 16 percent increase in the use of natural gas, and an 8 percent decrease in the use of oil by the commercial/institutional sector. Overall, fuel consumption will increase 4 percent between 1978 and 1985, a rate of increase that represents approximately 60 percent of that reported for the 1974 to 1978 period.

3.2 PROCESS CHARACTERISTICS

Most external combustion systems in the commercial sector are packaged units, including all firetube units. Field-erected units are, for the most part, restricted to very high capacity, high pressure watertube systems, usually found in the institutional sector.

TABLE 2. ANNUAL U.S. FUEL CONSUMPTION BY THE COMMERCIAL AND RESIDENTIAL SECTORS, ALL USES

Consuming sector	Fuel	Annual consumption (10^{18} joules)				
		1974	1975	1976	1977	1978
Commercial	Natural gas	2.77	2.78	2.92	2.75	2.93
	Coal	0.03	0.03	0.04	0.04	0.14
	Petroleum	3.09	2.83	3.00	2.99	3.05
	Total	5.89	5.64	5.96	5.78	6.12
Residential	Natural gas	5.46	5.62	5.79	5.51	5.58
	Coal	0.17	0.13	0.12	0.12	0.21
	Petroleum	3.04	3.01	3.33	3.30	3.33
	Total	8.67	8.76	9.24	8.93	9.12

Source: References 2, 8, 11.

TABLE 3. PERCENTAGE OF FUEL CONSUMPTION BY REGION IN THE COMMERCIAL SECTOR FOR 1978, PERCENT

Region	Percent consumption			
	Natural gas	Petroleum		Coal
		Distillate	Residual	
New England	2	20	19	nil
Mid-Atlantic	12	27	37	12
South Atlantic	10	35	16	10
East North Central	26	7	12	38
East South Central	6	1	1	12
West North Central	14	7	3	13
West South Central	11	< 1	2	1
Mountain	8	< 1	1	12
Pacific	11	3	9	2

Source: References 2 and 6.

TABLE 4. STATES CONSUMING THE LARGEST QUANTITIES OF PETROLEUM WITHIN THE COMMERCIAL/INSTITUTIONAL SECTOR IN 1974, 10^6 gal/yr

Residual oil		Distillate oil	
New York	2,532	Massachusetts	838
Massachusetts	1,315	New Jersey	728
Pennsylvania	711	Michigan	604
New Jersey	685	Texas	541
Maryland	222	Pennsylvania	443
		California	408

Source: Reference 7.

TABLE 5. COMMERCIAL/INSTITUTIONAL FUEL USE, 1978

Source category	Fuel use[a] (10^{15} joules)
Commercial/institutional	5,090
External combustion	5,040
Coal	140
Bituminous	90
Pulverized dry	20
Pulverized wet	< 1
All stokers	70
Anthracite	50
All stokers	50
Spreader stokers	0
Lignite	1
All stokers	1
Spreader stokers	0
Petroleum	2,600
Residual oil	1,400
Tangential firing	10
All other	1,390
Distillate oil	1,200
Tangential firing	10
All other	1,190
Gas	2,200
Tangential firing	15
All other	2,185
Refuse	100
Wood/Bark	100
Internal combustion	50
Petroleum	25
Gas	25

[a] Primarily for space heating, except internal combustion.

Source: References 2, 5 and 8.

To provide a better understanding of the emissions associated with commercial/institutional space heating combustion sources, brief descriptions of boiler types, installed capacities and fuel consumption data, and future market trends are provided below. Further details on these units can be found in References 3, 4, 8, and 12.

3.2.1 Warm Air Furnaces

Warm air furnaces for commercial applications burn gas or oil and are similar to those used for residential applications, although variations in design are more prevalent. Burners tend to be more versatile, with some units designed for a turndown capability of up to 25 to 1 to adjust to variable load requirements.[4] Heat exchangers also tend to be more efficient. Higher quality construction materials and larger interior volumes are other factors distinguishing commercial-size units from the residential units.

3.2.2 Cast Iron Systems

Except for their larger size, commercial cast iron units are similar to those used in the residential sector. Cast iron units are available with input capacities up to 14.2×10^9 J/hr and, similar to warm air furnaces, burn natural gas and distillate oil almost exclusively.[4] These systems require a very low level of maintenance and are highly reliable and durable. Cost, however, is generally higher than that of a comparable firetube boiler. In a cast iron system, combustion gases rise through a vertical heat exchanger and out through the exhaust duct. Water in the heat exchanger tubes is heated as it moves upward through the tubes. These systems are designed to supply low pressure steam or hot water.

3.2.3 Firetube Boilers

Although a large percentage of the smaller commercial units are cast iron, most of the commercial units with capacities from 5 to 26×10^9 J/hr are firetube boilers.[4,8] In firetube boilers, combustion products pass through tubes submerged in water. One or more passes can be used in the heat transfer section. Tube fouling resulting from the use of high ash fuels is avoided by the use of oil and gas as fuels. Residual oil is used in the larger sizes with distillate oil used primarily in smaller units. Firetube boilers are mainly of three design types: Scotch, firebox, and horizontal return tube. In the Scotch firetube, the most popular firetube boiler, the burner flame is contained in an elongated combustion chamber surrounded by water, and the rear wall is either refractory lined or water cooled. Mechanical drafts are required to compensate for the relatively small firetube diameter and the resulting high pressure drop through the heat exchanger. The improved heat transfer achieved in the Scotch boiler design results in lower heat transfer areas and greater compactness. Efficiencies of about 80 percent are achieved.

Firebox units are built with an internal, steel encased, water jacketed firebox. High efficiency (80 percent) and minimum floor space requirements are advantageous design features. However, sales of firebox units have dropped in recent years primarily because of difficulties in matching burner flame length to the small internal dimensions of the combustion chamber. High cost is also a factor in declining sales.[4]

Horizontal return tube units are comparatively inexpensive, but efficiencies resulting from poor water circulation seldom exceed 70 percent. Although at one time the most popular firetube boiler, it now accounts for only about 10 percent of existing firetube units.[4]

3.2.4 Watertube Boilers

In watertube boilers, the heat transfer tubes are designed for the flow of water instead of combustion products as in the firetube designs. Efficiencies attained are about 80 percent, without heat recovery. Boilers have a capacity of about 50 x 10^9 J/hr are almost exclusively watertube boilers. Watertube boilers also dominate the market where design steam pressures exceed 150 psig. They are inherently safer than firetube units at high pressures, primarily because of the smaller diameters of the pressurized tubes and their ability to accommodate expansion. Watertube boilers can either be packaged or field erected. Packaged units, which make up most of the units in the commercial/institutional sector, range in capacity from 10 to 250 x 10^9 J/hr. The trend is definitely towards the increased installation of packaged units; it is estimated that by 1990 about 99 percent of gas- and oil-fired watertube units installed in the size range of 10 to 100 x 10^9 J/hr will be packaged units.[4]

3.2.5 Atomization Methods for Oil-Fired Systems

The foregoing discussion classifies commercial/institutional external combustion systems in terms of combustion unit/heat transfer design. In oil-fired systems, the manner in which fuel is fed into the combustion chamber is an important design variable becasue these fuel feed variations may alter the nature of emissions.

There are four basic atomization methods: air atomization, steam atomization, mechanical atomization, and rotary cup atomization. Most air atomization burners used in commercial-size boilers are high pressure units. The oil flows through a central tube in the nozzle and the atomizing air flows in an annular tube around the oil passageway. Turbulent mixing of oil and atomizing air forms fine droplets. This mixing can occur either outside or inside the nozzle. Air atomization produces only about one-third of the particulate produced by steam atomization and one-thirteenth of the particulate from mechanical atomization.[4]

Steam-atomized burners are identical to high pressure air-atomized burners except that steam is used in place of pressurized air. The use of steam is practical if a supply of high pressure steam is readily available at the boiler.

High pressure mechanical atomization units operate by supplying oil at high pressure to one or more orifices in the nozzle. The design of the orifice influences the spray pattern and, to some degree, the droplet size. The flow channel to the orifice is oriented in such a way as to impart a high degree of swirl to the exiting oil. Combustion air flowing in an annular region around the oil channel is also given swirl before it mixes with the fuel outside the nozzle. The trend in small units is towards mechanical atomization (for simplicity) and in larger units towards air atomization.

Rotary cup burners use a rapidly rotating cup to which oil is supplied. Centrifugal force pushes the oil to the lip of the cup at which point it is dispersed in the form of tiny droplets. The mean droplet size decreases as the rotary speed is increased. Rotary burners are being phased out at present, primarily because of their high maintenance requirements.

3.2.6 Coal-Fired Systems

Generally, two major categories of coal-fired systems can be distinguished: (1) suspension firing and (2) grate firing. Suspension firing includes both pulverized coal units and cyclones. Grate firing consists of three major stoker types: underfeed, overfeed, and spreader stokers. There are several variations in feed method and grate design within these three types. Most commercial/institutional coal-fired boilers are stokers.[13]

The single retort underfeed stoker is the most prevalent of commercial size coal-fired units, accounting for about 80 percent of stoker capacity under 26.3×10^9 J/hr capacity.[8] Coal is fed to the bottom portion of a fuel bed; moisture and volatile hydrocarbons are driven off and pass up through the bed. Combustion of the volatile hydrocarbons occurs during passage through the bed. The coked coal is forced up through the bed and spills over into side grates where combustion is completed. Single retort underfeed stokers are used primarily for burning Eastern coking bituminous coals or other coals with high ash softening temperatures to avoid clinkering in the deep fuel beds.

Overfeed stokers are of the chain or traveling grate type. Fuel is fed to one end of the grate, which moves continuously toward the rear of the furnace, discharging ash and refuse. The links of the chain grate are assembled so that a scissoring action occurs when the grate goes over the end drums. This action tends to release ash or clinkers adhering to the chain, thus maintaining air flow through the belt. A wide variety of coals can be used, the notable exception being highly coking bituminous coals that tend to mat and restrict air flow through the fuel bed.

The spreader stoker is normally used for units with sizes well in excess of the commercial range. This type of stoker predominates in the capacity range of 50 to 250×10^9 J/hr. The spreader stoker consists of one or more feeder units, each comprising a hopper and a feeder that regulates the flow of coal into the hopper and distributes it across the grate. The stoker grate may be of the stationary, dumping, or continuous discharge type. The spreader stoker can burn a wider variety of fuels than any other stoker type. Coking properties of coals have little effect on performance.

Because of their complexity and resulting high cost, the practical lower capacity size limit of pulverized coal-fired boilers is about 100 x 10^9 J/hr.[12,13] Commercial/institutional pulverized units are primarily of the dry bottom type. There are very few pulverized wet bottom boilers used in the commercial sector. Operating characteristics of these units are described in more detail in Reference 12.

3.2.7 Internal Combustion Units

Internal combustion sources can be classified into two types based on their method of transformation of fluid energy into mechanical work or power. The two classifications are gas turbines and reciprocating engines.

In the commercial/institutional sector, reciprocating engines are used primarily for pumping municipal water and sewage. Gas turbines are seldom used by municipalities. A small number of engines, from the standpoint of fuel consumption, are used for emergency power generation. The reciprocating engine may be classified according to the method of ignition into spark ignition or compression ignition engines. Spark ignition engines use either gas or volatile liquids such as gasoline as fuels. Compression-type engines use low volatility fuels such as distillate oil and kerosene. Some compression ignition engines are dual-fired engines, burning any mixture ratio of gas and diesel fuel. A more detailed description of reciprocating engines can be found in References 14, 15 and 16.

3.3 NUMBER, CAPACITY DISTRIBUTION, AND EMISSION CHARACTERISTICS

Estimates of the number and capacity of commercial/institutional boilers have been derived from data in EPA's National Emissions Data System (NEDS), from sales records of the American Boiler Manufacturers Association, and from other trade organizations.[4,5,8,13,15,16,17] The number of commercial/institutional boilers is estimated to be about 1,300,000[8] to 1,500,000.[5,13] It has been further estimated, based on NEDS data, that the capacity median size of commercial/institutional residual oil-fired boilers is 26.4 x 10^9 J/hr, with boilers in the 18 to 37 x 10^9 J/hr size range constituting the 40 to 60 percentile. The capacity median sizes of gas-fired and distillate oil-fired units are 19 and 4.2 x 10^9 J/hr, respectively.[13] Commercial/institutional watertube units are occasionally fueled by coal, primarily stoker-fired. Pulverized coal units because of their complexity are generally available only in sizes greater than 100 x 10^9 J/hr input.[13] Watertube boilers in the commercial/institutional sector are fired by oil (45 percent), natural gas (30 percent), or coal (25 percent).[5] All firetube boilers are gas- or oil-fired.

The population distribution of commercial size boilers by boiler type and by fuel capability is shown in Tables 6 and 7, respectively. Trend information by boiler types, provided in Reference 17, indicates that by 1990 all firetube boilers will be of the Scotch or firebox type with only minor changes in the use of cast iron and watertube units. Fuel trend estimates were also provided in Reference 17, indicating appreciable growth in the use of coal and dual-fired units. The population distribution of oil-fired commercial boilers by burner type is shown in Table 8. This table, based on 1972 data, is misleading because rotary burners, which made up a significant fraction of the burners in service for larger units in 1972, are rapidly being phased out of service and will be replaced entirely by air and mechanical atomizing burners by 1990.[17]

Reciprocating engines used in the commercial/institutional sector are medium-size engines with an average capacity of about 400 hp.[15] Approximately 4,000 engines are currently in use by municipalities for water pumping and sewage treatment. Approximately 25 x 10^{15} J of natural gas and 25 x 10^{15} J of oil are used annually for these applications.[5,18]

Information concerning the age of commercial/institutional units is limited. A recent study[8] reported that initial estimates of boiler age were inconclusive and that extensive effort will be required to develop adequate information on boiler age. The same study reported that existing data concerning thermal input rates and annual load factors are also inconclusive.

TABLE 6. POPULATION DISTRIBUTION OF COMMERCIAL BOILERS BY BOILER TYPE, 1972, PERCENT

Type of unit	Rated capacity (10^9 J/hr)		
	0.4 to 2.0	2.0 to 4.0	4.0 to 13
Watertube	6	8	5
Firetube			
Scotch	15	20	30
Firebox	25	25	30
Horizontal return tube	5	10	15
Other	3	3	5
Cast iron	45	33	15
Miscellaneous (tubeless, etc.)	1	1	nil
Total	100%	100%	100%

Source: Reference 17.

TABLE 7. POPULATION DISTRIBUTION OF COMMERCIAL BOILERS BY TYPE OF FUEL, 1972, PERCENT

Type of fuel	Rated capacity (10^9 J/hr)		
	0.4 to 2.0	2.0 to 4.0	4.0 to 13
All fuels			
Oil only	42	42	40
Gas only	50	50	50
Coal only	2	1	1
Oil and gas	5	6	8
Miscellaneous fuels	1	1	1
Total	100%	100%	100%
Oil			
Distillate, No. 2	95	85	50
Residual	5	15	50
Total	100%	100%	100%

Source: Reference 17.

TABLE 8. POPULATION DISTRIBUTION OF OIL-FIRED COMMERCIAL BOILERS BY BURNER TYPE, 1972, PERCENT

Burner type	Rated capacity (10^9 J/hr) 0.4 to 2.0	2.0 to 4.0	4.0 to 13
Air atomizing	15	35	40
Pressure or mechanical atomizing	70	25	20
Rotary	15	40	40
Total	100%	100%	100%

Source: Reference 17.

In general, small watertube, firetube, and cast iron boilers, fired by single burners, have similar combustion characteristics and, thus, similar emission factors.[19] Air pollution control equipment is generally not installed on commercial/institutional boilers and internal combustion engines, although some larger institutional boilers, particularly those burning coal, do have controls. Overall particulate control efficiency is estimated to be 40 percent for bituminous, pulverized dry bottom boilers and 20 percent for all stokers based on data available in NEDS. Gas- and oil-fired units are essentially uncontrolled. Proper attention to maintenance and operating practices, and the use of low emission burners can reduce emissions. Burner modulation, instead of on/off cyclic operation, will also reduce emissions by eliminating particulate, HC and CO emission peaks that occur during ignition and after burner shutdown.

4.0 EMISSIONS

Air emissions from flue gas stacks represent the only significant emissions from commercial/institutional combustion sources. Pollutants emitted in flue gas streams include particulates, NO_x, sulfur oxides (SO_x), sulfates, CO, trace elements, and a variety of organic materials including POM. Trace elements in the flue are mostly emitted as particulates. The notable exceptions are volatile elements, e.g., mercury and halogens, which are emitted in gaseous form. Fugitive emissions from the commercial/institutional sector are of little importance. Emissions from coal storage and ash piles are minor because of the small amount of coal used; evaporation losses from liquid fuels are also minor because of their relatively low volatility; and gaseous fuels are contained before combustion.

Overall, commercial/institutional combustion sources, based on the types and quantities of fuel burned, are only minor contributors to the nationwide emission burden. Compared to residential heating sources, commercial/institutional sources are larger but much less numerous, the source receptor relationship is less close, and stacks are higher, thus promoting more rapid dispersion of pollutants. However, as with residential sources, commercial/institutional sources are essentially uncontrolled, and they are not considered to be as well maintained and operated as larger industrial and utility combustion sources. This lack of control combined with poor maintenance and operating practices can lead in some instances to excess emissions of potentially hazardous pollutants; e.g., certain organic species and particulates.

Detailed characterization data on flue gas emissions from commercial/institutional combustion sources are discussed in following sections. Fugitive air emissions and pollutant emissions to water from the larger institutional sources represent less than 1 percent of such emissions from conventional combustion sources and will not be discussed in this report.

4.1 EVALUATION OF EXISTING EMISSIONS DATA

4.1.1 Criteria for Evaluating the Adequacy of Emissions Data

A major task in this program was to identify gaps and inadequacies in the existing emissions data base for combustion sources. The results of this effort determined the extent of the sampling and analysis program required to complete an adequate emissions assessment for each of the combustion-source types. In addition, the data acquired during the sampling and analysis program, in combination with the existing data, also needed to be assessed. Data inadequacies identified at the completion of the current program will require further study.

The criteria for assessing the adequacy of emissions data are developed by considering both the reliability and variability of the data. A detailed presentation of the procedures used to identify and evaluate emissions data is given in Appendix A. Briefly, the general approach is to use a three-step process. In the first step, the available data are screened for adequate definition of process and fuel parameters that may affect emissions, as well as for validity and accuracy of sampling and analysis methods. In the second step of the data evaluation process, emission data deemed acceptable in Step 1 are subjected to further engineering and statistical analysis to determine the internal consistency of the test results and the variability in emission factors. The third and final step in the process uses a method developed by Monsanto Research Corporation (MRC), which is based on both the potential environmental risks associated with the emission of each pollutant and the quality or variability of the data. The potential environmental risks associated with pollutant emissions are determined by the use of an ambient severity factor that is defined as the ratio of the calculated maximum ground-level concentration of the pollutant species for an isolated typical source to the level at which a potential environmental hazard exists. Data variability, V, is defined as

$$V = t\,\frac{s(\bar{x})}{\bar{x}}$$

where $s(\bar{x})$ is the standard deviation of the mean and $\bar{x}$ is the estimated mean value. Defined in this manner, data variability is a measure of the "relative precision" of the estimated mean emission factor, assuming a normal distribution of emission factors (see Appendix A). If the variability of emission factor data is < 70 percent, (equivalent to an accuracy factor of < 3, which has been defined by EPA as the acceptable accuracy for Level I sampling and analysis), the data are deemed adequate. However, if the variability of the emissions data is > 70 percent, the determination of data adequacy and the need for further measurement will be based on calculated ambient severity factors for each pollutant. The data will be considered adequate if the upper bound of the ambient severity factor is ≤ 0.05.

In addition to the general approach described above, fuel analysis, mass balance, and physico-chemical considerations can often be used to estimate emission levels and to establish the adequacy of the data base. For example, flue gas emissions of trace elements from oil-fired boilers can be determined from the trace element content of fuel oil by mass balance. Thus, an adequate characterization of the trace element content of fuel oil will provide an adequate characterization of trace element emissions from oil-fired boilers. Fuel sulfur content, ash content of coal, and the nitrogen content of residual oil are other examples of fuel characteristics that can be used to estimate emissions from combustion sources. EPA emission factors given in Reference 24 (AP-42) for particulates, SO_x, and NO_x are dependent to varying degrees on certain of the above fuel characteristics. Certain combustion system characteristics, e.g., size, load, burner type, and other operational parameters, also affect emissions of some criteria pollutants. These effects are quantified in AP-42 for some combustion source categories.

Both fuel and combustion system characteristics are important factors affecting criteria pollutant emissions, and the magnitude of these factors can be determined for combustion source categories under representative combustion conditions by examining EPA emission factors.[24] However, the existing emissions data base is too limited to allow estimation of criteria pollutant emissions under nonrepresentative or abnormal conditions of combustion source operation, nor is it possible to quantify emissions of certain pollutants, e.g., POM, under any conditions. Although emissions of POM are known to be dependent on such factors as fuel, burner efficiency, and load, the magnitude of such factors cannot be assessed given our present state of knowledge of emissions from combustion sources. A major objective of this program is to provide additional data for use in the assessment of the significance of POM and other emissions from representative combustion source categories using the general approach described previously.

4.1.2 Existing Emissions Data: Gas-Fired Sources

Criteria pollutant emissions data for commercial size gas-fired boilers have been obtained by Battelle[20,21] and KVB Engineering, Inc.[22,23] The Battelle data were obtained at baseline conditions (approximately 80 percent load and 10 percent CO_2) for representative commercial units that include one watertube, four firetube, and two cast iron boilers. Input capacities of these units ranged from 1.7 to 16.7 x 10^9 J/hr. The KVB data for one watertube and seven firetube sources were also obtained at approximately baseline conditions. Although the units studied by KVB were classified as industrial boilers, they have been included in the data base because of their small size (input capacities less than 18.5 x 10^9 J/hr). A summary of the criteria pollutant emission data is shown in Table 9. The number of data points, average emission factor, variability of the emission factor, ambient severity factor, data base adequacy, and the published EPA emission factor[24] are presented in this table.

As shown in Table 9, the criteria pollutant data base is adequate for gas-fired commercial systems. Despite the high variability of HC and CO emissions, the upper limit of the ambient severity factors for these pollutants is well below 0.05. The only criteria pollutant of potential environmental significance is NO_x, with a mean severity factor approaching 0.05.

Particle size distribution, sulfate, SO_3, and trace element emissions data were not found in the literature for gas-fired commercial sources. KVB Inc.,[22] however, did attempt to determine the particle size distribution of fly ash from six larger gas-fired industrial systems by optical classification. Two different types of particle size distribution were found: for three boilers most particulates were less than 6 μm; for the other three boilers most were greater than 6 μm. The results must be considered inconclusive because of difficulties in counting small (< 2 μm) particulates by the optical techniques used. The lack of particle size distribution data, along with a total lack of literature data dealing with sulfate, SO_3, and trace element emissions, does not represent a serious deficiency because of the relatively low particulate emissions from gas-fired sources and the low sulfur and trace element contents of natural gas.

TABLE 9. SUMMARY OF EMISSIONS DATA FOR GAS-FIRED COMMERCIAL SIZE BOILERS

Pollutant	Number of units	Mean emission factor (ng/J)	Variability (%)	Ambient severity factor[a]	Data base adequacy[b]	EPA emission factor[c] (ng/J)
Particulates	9	2.4	65	0.0006	A	2-6
SO_2	5	0	0	< 0.0001	A	0.26[d]
NO_x	15	41	14	0.046	A	33
HC	12	5.8	121	0.0058[e]	A	3
CO	15	12	85	< 0.0001[e]	A	8

[a] Based on a firing rate of 6.9 x 10^9 J/hr.

[b] Adequate data base is indicated by A.

[c] Reference 24.

[d] Based on a fuel sulfur content of 4,600 g/10^6 Nm^3.

[e] Upper limit ambient severity factor.

The Public Health Service measured emissions of POM from two commercial/institutional gas-fired sources, as shown in Table 10. Samples were obtained by passing the flue gas through two water impingers at 0°C, a series of freeze out traps at -17°C, and a high-efficiency filter. The samples were then extracted with benzene and separated by chromatography. Concentrations of several specific compounds were measured by ultraviolet-visible spectroscopy. Because there is only one measurement for two source types, no meaningful measurement of variability is possible. The Scotch boiler was operating at about 25 percent of rated capacity, which may account for emissions that are higher than those from the firetube boiler, which was operated in excess of its rated capacity.

TABLE 10. POM EMISSIONS FROM GAS-FIRED COMMERCIAL/INSTITUTIONAL SOURCES, pg/J

Pollutant	Combustion source	
	Firetube boiler, 9.8 GJ/hr input	Scotch marine boiler, 1.0 GJ/hr input
Total benzene-soluble organics	1040	1140
Benzo(a)pyrene	< 0.02	0.2
Pyrene	0.004	17.4
Benzo(e)pyrene	0.014	0.5
Perylene	ND	ND
Benzo(g,h,i)pyrene	ND	1.7
Anthanthrene	ND	0.2
Coronene	0.012	5.1
Anthracene	ND	ND
Phenanthrene	ND	ND
Fluoranthene	0.09	2.8

ND - Not detected.

Source: Reference 25.

Generally, emissions of POM are not of concern because of the paraffinic nature of natural gas and the large amount of excess air normally used in commercial/institutional boilers. Other things being equal, the tendency for hydrocarbons to form POM is

Aromatics > Cycloolefins > Olefins > Paraffins

Natural gas contains predominantly saturated hydrocarbons, which do not promote addition-type reactions between hydrocarbon species. Also, the absence of ring structure-type compounds in natural gas means that there are no convenient building blocks for more condensed ring structures such as POM. However, in view of the severity of POM exposure and the deficiency of data, further testing for POM from natural gas-fired sources should be conducted to confirm their lack of significant impact as sources of these pollutants.

4.1.3 Existing Emissions Data: Oil-Fired Sources

Battelle[20,21] and KVB[22,23] also investigated criteria pollutant emissions from oil-fired sources of small to moderate size at baseline conditions (approximately 80 percent load and 12 percent CO_2). Battelle reported emission data for two cast iron, one watertube, and five firetube boilers burning No. 2 distillate oil. KVB reported data on five firetube and two watertube industrial boilers with input capacities less than 17 x 10^9 J/hr. A summary of the combined Battelle and KVB data is shown in Table 11. The data have been combined because the combustion characteristics of cast iron, firetube, and small watertube boilers are similar and, thus, emission factors should be similar.[4] The KVB data[22,23] also indicate that burner and boiler type and size have little effect on emission factors.

TABLE 11. SUMMARY OF EMISSIONS DATA FOR DISTILLATE OIL-FIRED COMMERCIAL SIZE BOILERS

Pollutant	Number of units	Mean emission factor (ng/J)	Variability (%)	Ambient severity factor[a]	Data base adequacy[b]	EPA emission factor[c] (ng/J)
Particulates	11	5.5	67	0.0018	A	6.2
SO_2	8	389S	17	0.025	A	106[d]
NO_x	15	51.3	19	0.076	A	68
HC	11	2.2	137	0.0017[e]	A	3
CO	12	3.2	100	< 0.0001[e]	A	15

[a] Based on an average firing rate of 9.1 x 10^9 J/hr.

[b] Adequate data base is indicated by A.

[c] Reference 24.

[d] Based on an average fuel sulfur content of 0.25 percent.

[e] Upper limit ambient severity factor.

The criteria pollutant emission data base is adequate for distillate oil-fired commercial size boilers. The high variability of HC and CO, as found previously for gas-fired sites, is most likely an indication of the inherent variability in the emissions of these pollutants from commercial size combustion systems. Based on the ambient severity factor, NO_x emissions are the most significant of the criteria pollutant emissions.

Criteria pollutant emissions data for the firing of No. 6 residual oil at baseline conditions were also obtained by Battelle[20,21] and KVB.[22,23] Battelle reported emissions from one cast iron, two watertube and six firetube boilers with input capacities ranging from 4.2 to 25 x 10^9 J/hr. KVB reported data for one firetube and four watertube boilers with input capacities ranging from 7 to 16 x 10^9 J/hr. The data from these studies have been combined and are shown in Table 12. The emissions data are adequate for all pollutants, with NO_x, based on the ambient severity factor, the only pollutant of potential environmental significance.

TABLE 12. SUMMARY OF EMISSIONS DATA FOR NO. 6 RESIDUAL OIL-FIRED COMMERCIAL SIZE BOILERS

Pollutant	Number of units	Mean emission factor (ng/J)	Variability (%)	Ambient severity factor[a]	Data base adequacy[b]	EPA emission factor[c] (ng/J)
Particulates	10	49.9	47	0.019	A	37[d]
SO_2	11	438S	7	0.012	A	450S
NO_x	15	166	20	0.29	A	172
HC	12	1.1	96	0.001[e]	A	3
CO	15	2.1	97	< 0.0001[e]	A	15

[a] Based on a firing rate of 10.4 x 10^9 J/hr.

[b] Adequate data base is indicated by A.

[c] Reference 24.

[d] Based on a national average fuel sulfur content of 1.03 percent.[26]

[e] Upper limit ambient severity factor.

Particle size distribution data were obtained by Battelle[20] for two boilers firing No. 6 fuel oil. The mass mean aerodynamic diameters obtained were 0.5 and 1.2 μm. KVB[23] also measured the particulate mass mean aerodynamic diameter from oil-fired sources. Mass mean diameters ranged from 0.4 to 5.5 μm for five determinations for boilers using various fuel oils. KVB estimated that, on the average, 24 percent of the particulate from oil-fired boilers is less than 0.5 μm and that 67 percent of the total particulate is inhaled and retained in the respiratory passages.[23]

The literature contains very little data concerning the emission of sulfates and SO_3 from oil-fired commercial size sources. Data obtained by KVB indicate that sulfate emissions are of little significance for industrial boilers and the ratio of SO_3 to SO_x is typically 1 to 2 percent.[23] Although data obtained by KVB show a sharp increase in SO_3 at low total SO_x concentrations, the apparent effect was attributed to inadequacies in the measurement method at low SO_3 concentrations. This conclusion is supported by the fact that the rate of formation of SO_3 is directly proportional to SO_2 concentrations. The formation of SO_3 is also favored by increased combustion oxygen. The high excess oxygen levels found in commercial source flue gases could lead to higher than normal levels of SO_3 and sulfates. Only one set of particulate sulfate and SO_3 emission data from an institutional source was found in the literature.[26] During the measurement period this large institutional boiler (100×10^9 J/hr) was burning a 2.2 percent sulfur residual oil fuel containing 350 ppm vanadium at excess air levels of about 30 percent. Conversion of fuel sulfur to total sulfate (particulate sulfate and SO_3) was 4.5 percent as determined by Goksöyr-Ross procedures. This relatively high conversion may be caused by the high vanadium content of the fuel because vanadium is a fuel sulfur oxidation catalyst. Conversion of SO_3 to particulate sulfate was found to be a function of sampling rate. When the sampling rate was increased, the ratio of SO_3 to particulate sulfate increased from 0.67 to about 4 over the range of sampling velocities studied. These data indicate that considerable care must be exercixed when interpreting total sulfate emission data obtained by present test methods.

Assuming a 1.5 percent conversion of total sulfur in the flue gas to SO_3, the SO_3 emission factor for residual oil is 7 ng/J and the ambient severity factor is 0.18. On this basis, SO_3 emissions from residual oil combustion represent an environmental problem.

The trace element data base for commercial oil-fired systems is limited to data obtained by Battelle[20] for a firetube boiler burning residual oil. However, emissions of trace elements from oil combustion can be computed from the trace element concentration of the oil feed by assuming that all elements are emitted from the stack. Average trace element contents of residual oil, based on a weighted average of U.S. crudes (domestic and imported),[27] are presented in Table 13. Emission factors and mean source severities calculated from these trace element concentrations are shown in Table 14. Elements with ambient severity factors greater than 0.05 are beryllium, cadmium, cobalt, nickel, and vanadium. Emissions of these trace elements from residual oil-fired commercial sources appear to be environmentally significant, and the data base for these elements must be considered inadequate.

Trace element concentration data for distillate oil are limited, and computation of emission factors and ambient severity factors was not attempted. Trace element emissions, however, will generally be lower than those resulting from residual oil combustion.

The Public Health Service measured the emissions of POM from three commercial/institutional oil-fired heating units, as shown in Table 15. For the measurements shown in Table 15, the Public Health Service obtained samples by passing the flue gas through two water impingers at 0°C, a series of freeze-out traps at -17°C, and a high-efficiency filter. The samples were then extracted with benzene and separated by chromatography. Concentrations of several specific compounds were measured by ultraviolet-visible spectroscopy. Variability data have not been calculated because of the limited number of tests and the variations in boiler type and load.

TABLE 13. AVERAGE TRACE ELEMENT CONCENTRATIONS OF RESIDUAL OIL

Trace element	Concentration (ppm)	Trace element	Concentration (ppm)
Vanadium	160	Gallium	0.4
Nickel	42.2	Indium	0.3
Potassium	34	Silver	0.3
Sodium	31	Germanium	0.2
Iron	18	Thallium	0.2
Silicon	17.5	Zirconium	0.2
Calcium	14	Strontium	0.15
Magnesium	13	Bromine	0.13
Chlorine	12	Fluorine	0.12
Tin	6.2	Ruthenium	0.10
Aluminum	3.8	Tellurium	0.1
Lead	3.5	Cesium	0.09
Copper	2.8	Beryllium	0.08
Cadmium	2.27	Iodine	0.06
Cobalt	2.21	Lithium	0.06
Rubidium	2	Mercury	0.04
Titanium	1.8	Tantalum	0.04
Manganese	1.33	Rhodium	0.03
Chromium	1.3	Gold	0.02
Barium	1.26	Platinum	0.02
Zinc	1.26	Scandium	0.02
Phosphorus	1.1	Bismuth	0.01
Molybdenum	0.90	Cerium	0.006
Arsenic	0.8	Tungsten	0.004
Selenium	0.7	Hafnium	0.003
Uranium	0.7	Yttrium	0.002
Antimony	0.44	Niobium	0.001
Boron	0.41		

Source: Reference 27.

TABLE 14. TRACE ELEMENT EMISSION FACTORS AND MEAN AMBIENT SEVERITY FACTORS FOR RESIDUAL OIL-FIRED BOILERS

Trace element	Concentration (ppm)	Emission factor (pg/J)	Ambient severity factor[a]
Aluminum (Al)	3.8	87	< 0.001
Arsenic (As)	0.8	18	0.022
Boron (B)	0.41	9.4	< 0.001
Barium (Ba)	1.26	28.8	0.004
Beryllium (Be)	0.08	1.8	0.055
Bromine (Br)	0.13	3.0	0.001
Calcium (Ca)	14	320	0.004
Cadmium (Cd)	2.27	51.9	0.063
Chlorine (Cl)	12	274	0.006
Cobalt (Co)	2.21	50.5	0.062
Chromium (Cr)	1.3	30	0.036
Copper (Cu)	2.8	64	0.004
Fluorine (F)	0.12	2.7	< 0.0001
Iron (Fe)	18	411	0.005
Mercury (Hg)	0.04	0.9	0.001
Potassium (K)	34	777	0.023
Lithium (Li)	0.06	1.4	0.004
Magnesium (Mg)	13	297	0.002
Manganese (Mn)	1.33	30.4	< 0.0001
Molybdenum (Mo)	0.9	21	< 0.0001
Sodium (Na)	31	708	0.017
Nickel (Ni)	42.2	964	0.59
Phosphorus (P)	1.1	25	0.002
Lead (Pb)	3.5	80	0.033
Antimony (Sb)	0.44	10	0.001
Selenium (Se)	0.7	16	0.005
Silicon (Si)	17.5	400	0.002
Tin (Sn)	6.2	142	0.002
Strontium (Sr)	0.15	3.4	< 0.0001
Thorium (Th)	<0.001	<0.02	< 0.0001
Uranium (U)	0.7	16	0.05
Vanadium (V)	160	3656	0.45
Zinc (Zn)	1.26	28.8	< 0.0001

[a] Based on a firing rate of 25 x 10^9 J/hr.

TABLE 15. POM EMISSIONS FROM OIL-FIRED COMMERCIAL/ INSTITUTIONAL SOURCES, pg/J

Pollutant	Combustion source		
	Watertube boiler,[a] 22 GJ/hr input	Watertube boiler,[b] 15 GJ/hr input	Scotch marine boiler,[c] 0.74 GJ/hr input
Total benzene-soluble organics	1,320	3,130	13,270
Benzo(a)pyrene	< 0.02	0.05	0.9
Pyrene	0.04	0.3	5.8
Benzo(e)pyrene	ND	ND	ND
Perylene	ND	ND	ND
Benzo(g,h,i)pyrene	ND	ND	0.3
Anthanthrene	ND	ND	ND
Coronene	ND	ND	2.0
Anthracene	ND	ND	3.7
Phenanthrene	ND	1.8	3.3
Fluoranthene	0.05	0.3	1.8

ND — Not detected.

[a] No. 2 fuel oil, 73 percent load.

[b] No. 6 fuel oil, 38 percent load.

[c] No. 1 fuel oil, 15 percent load.

Source: Reference 25

Battelle[21] also measured benzo(a)pyrene emissions from four Scotch boilers burning Nos. 4, 5, and 6 fuel oil at baseline conditions. The average emission factor was 0.95 pg/J, a value very similar to the maximum value measured by the Public Health Service. However, the data base is small, and further POM emission measurements are needed.

4.1.4 Existing Emissions Data: Coal- and Wood-Fired Sources

The existing emissions data for coal- and wood-fired commercial/institutional boilers are particularly deficient. **No recent criteria pollutant emissions data were found,** although there has been some work done on small experimental pulverized and stoker units. These studies were designed to test the effect of operating parameters on emissions, but the results cannot be applied to existing commercial/institutional units because of differences in unit design and capacity.

Criteria pollutant emission factors from AP-42 and the corresponding ambient severity factors are shown in Table 16 for solid fuel-fired souces. The factors were calculated using the fuel and combustion system data provided in the footnotes to the table. Ambient severity factors for bituminous coal-fired systems are significant for all pollutants with the exception of CO and HC from large pulverized dry units. However, because no variabilities are available , emissions data for all criteria pollutants from these bituminous-fired systems must be considered inadequate. Similarly, the data base for anthracite stokers and wood-fired boilers, with the exception of CO emission data, must be considered inadequate.

Particle size distribution, SO_3 and sulfate, and trace element emissions data for solid fuel-fired commercial/institutional sources are also not available in the literature, and the data base for these pollutants is therefore inadequate. However, it is possible to draw analogies in some cases from data obtained for utility and industrial boilers. Particle size distribution data for utility sources have been discussed in some detail in Volume III of this Emissions Assessment of Conventional Stationary Combustion Systems program report series.[28] Particulate emissions from pulverized dry bottom and spreader stoker units were reported to have similar size distributions, with

TABLE 16. CRITERIA POLLUTANT EMISSION FACTORS[a] (AP-42) AND AMBIENT SEVERITY FACTORS[b] FOR COAL- AND WOOD-FIRED COMMERCIAL COMBUSTION SYSTEMS

Combustion system	Criteria pollutant									
	Particulates		SO_2		NO_x		HC		CO	
	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor
Bituminous, pulverized dry bottom	332A[c]	3.6	743S[c]	0.8	352	1.2	6	0.01	20	< 0.0001
Bituminous stokers										
Underfeed stokers	39A	0.2	743S	0.4	117	0.2	59	0.05	196	0.0008
Spreader stoker	254A	1.4	743S	1.0	293	1.3	20	0.05	39	< 0.0001
All other stokers	98A	0.5	743S	0.4	-	-	-	-	-	-
Anthracite stokers	15A	0.6	551S	0.07	145	0.2	nil	-	15	< 0.0001
Wood stokers	215-645	0.08-0.2	65	0.02	140	0.7	86-3010	0.07-2.6	86-2580	< 0.0001

[a] From AP-42, Reference 24: Based on heating value of 25,586 kJ/kg (11,000 Btu/lb) for bituminous coal; **34,500 kJ/kg (14,833 Btu/lb) for anthracite coal**; and 10,527 kJ/kg (4,545 Btu/lb) for wood.

[b] Based on the following ash and sulfur contents: bituminous coal - A = 14.09%, S = 1.92%; anthracite coal - A = 10%, S = 0.57%; and input capacities of 100 x 10^9 J/hr for bituminous, pulverized dry; 50 x 10^9 J/hr for bituminous spreader stoker; and 10 x 10^9 J/hr for all other systems. The ambient severity factor is defined as the ratio of the calculated maximum ground level concentration of the pollutant species to the level at which a potential hazard exists. A value greater than 0.05 indicates a potential problem.

[c] A = Ash content in percent; S = Sulfur content in percent.

AP-42

about 1 percent by weight of the particulates in the less than 1 μm size fraction and the bulk of the particulates (78 to 90 percent) in the greater than 10 μm fraction. Oil-firing produces much finer particulates than coal-firing, with 35 percent by weight in the less than 1 μm fraction and only 13 percent by weight in the greater than 10 μm fraction.[28] Similar data for oil-firing were reported by KVB,[23] as previously noted. Particle size distribution data for commercial/institutional sources are expected to be similar to those found for larger utility and industrial boilers, although differences may occur as the result of the lower combustion efficiency and higher excess air levels found in commercial units.

Emissions of SO_3 and sulfates from commercial combustion systems are also expected to be analogous to those found in the flue gases of larger size combustion systems. Existing data for coal-fired utilities show that the percent conversion of fuel sulfur to primary sulfate is about 1.5 percent with approximately equal amounts of fuel sulfur converting to particulate sulfate and SO_3.[28] Again, operational differences could cause variations in emission levels. Higher excess air levels in commercial units, for example, would favor increased emissions of both SO_3 and sulfates. However, the increase is expected to be marginal and would have little effect on nationwide emissions of these pollutants.

Trace element emissions from commercial/institutional coal-fired units should closely parallel trace element emissions from uncontrolled coal-fired utility and industrial combustion systems. Emission factors and source severities for uncontrolled bituminous, pulverized dry bottom and underfeed stoker units and for anthracite stokers are presented in Table 17. The data shown in the table were based on information presented in Reference 28 for utility boilers and assume that trace element enrichment factors and concentrations in the coal burned are similar for utility and commercial/institutional combustion systems. Source severities calculated for the uncontrolled coal-fired sites are high, with the emissions of several elements associated with severity factors appreciably greater than 0.05. The trace element emissions data base for coal-fired commercial/institutional combustion systems must be considered inadequate because of the absence of data and the potential significance of emissions.

TABLE 17. TRACE ELEMENT EMISSION FACTORS AND MEAN AMBIENT SEVERITY FACTORS FOR COAL-FIRED COMMERCIAL/INSTITUTIONAL BOILERS

	Combustion source type					
	Bituminous, pulverized dry bottom[a]		Bituminous stoker, underfeed[b]		Anthracite stoker[c]	
Trace element	Emission factor (ng/J)	Ambient severity factor[d]	Emission factor (ng/J)	Ambient severity factor[d]	Emission factor (ng/J)	Ambient severity factor[d]
Aluminum (Al)	397	2.4	50	0.012	42	0.010
Arsenic (As)	1.2	1.5	0.1	0.050	0.05	0.024
Boron (B)	4.1	0.026	0.5	0.002	0.04	0.001
Barium (Ba)	4.2	0.51	0.5	0.024	0.2	0.010
Beryllium (Be)	0.1	3.1	0.01	0.12	0.007	0.084
Bromine (Br)	0.34	0.031	0.34	0.014	-	-
Calcium (Ca)	263	3.2	33	0.15	2.4	0.012
Cadmium (Cd)	0.08	0.098	0.01	0.049	0.001	0.005
Chlorine (Cl)	33.9	0.69	33.9	0.28	11.9	0.10
Cobalt (Co)	0.4	0.49	0.05	0.026	0.03	0.016
Chromium (Cr)	2.6	3.1	0.3	0.15	0.2	0.10
Copper (Cu)	1.1	0.067	0.1	0.002	0.04	<0.001
Fluorine (F)	13.5	0.41	13.5	0.16	0.7	0.008
Iron (Fe)	393	4.8	49	0.24	12	0.003
Mercury (Hg)	0.007	0.008	0.007	0.003	0.002	<0.001
Potassium (K)	53	1.6	6.6	0.081	4.6	0.056
Lithium (Li)	1.13	3.1	0.1	0.11	0.04	0.044
Magnesium (Mg)	57	0.35	7.2	0.018	0.8	0.002
Manganese (Mn)	1.8	0.022	0.2	<0.001	0.08	<0.001
Molybdenum (Mo)	0.5	0.006	0.06	<0.001	0.01	<0.001
Sodium (Na)	24	0.58	3.0	0.029	0.9	0.010
Nickel (Ni)	2.9	1.8	0.4	0.24	0.2	0.12
Phosphorus (P)	4.9	0.30	0.6	0.025	0.4	0.016
Lead (Pb)	0.9	0.37	0.1	0.016	0.04	0.006
Antimony (Sb)	0.2	0.024	0.02	<0.001	0.01	<0.001
Selenium (Se)	0.3	0.092	0.04	0.005	0.02	0.002
Silicon (Si)	711	4.3	89	0.21	52	0.12
Tin (Sn)	0.5	0.006	0.06	<0.001	0.05	<0.001
Strontium (Sr)	7.0	0.14	0.9	0.007	0.2	0.002
Thorium (Th)	0.06	0.087	0.008	0.005	0.01	<0.001
Uranium (U)	0.04	0.012	0.005	0.001	0.004	<0.001
Vanadium (V)	1.3	0.16	0.2	0.010	0.07	0.004
Zinc (Zn)	2.0	0.024	0.3	0.001	0.03	<0.001

[a] Uncontrolled emissions calculated from data in Reference 28, Table 59.

[b] Uncontrolled emissions calculated from bituminous, pulverized dry bottom emission factors and ratio of AP-42 emission factors[24] for the two combustion source types.

[c] Uncontrolled emissions based on trace element concentration data in Reference 28, Table 46, and the AP-42 emission factor.[24]

[d] Calculated using the combustion parameters and coal characteristics in the footnotes to Table 16. Ambient severity factor is defined as the ratio of the calculated maximum ground level concentration of the pollutant species to the level at which a potential environmental hazard exists. A value greater than 0.05 indicates a potential problem.

Trace element emissions data for wood-fired commercial/institutional systems were not found in the literature. The trace element emissions data base for wood-fired sources is, therefore, inadequate.

POM emissions data for commercial/institutional coal-fired sources are limited to data obtained by Hangebrauck et al.[25] and data obtained by Battelle using various coals in an experimental underfeed stoker unit.[29] No data were found for wood-fired sources. Data were reported in Reference 25 for two bituminous-fired underfeed stokers tested at input heat levels of 2.8 and 4.2 x 10^9 J/hr. The data from Reference 25 are presented in Table 18, along with data obtained in the same study for a pulverized, dry bottom industrial boiler burning bituminous coal at an energy input rate of 123 x 10^9 J/hr. The sampling and analytical techniques used to measure POM emissions were identical to those previously described in the discussion of POM emissions from gas- and oil-fired commercial systems.

The Battelle data show POM emissions to be a function of coal type and suggest a relationship between POM emissions and the volatile matter in coal. The maximum POM emission value reported was 6000 pg/J for a bituminous coal of high volatility. The POM emissions data base is obviously inadequate and further testing is required.

TABLE 18. POM EMISSIONS FROM BITUMINOUS COAL-FIRED COMMERCIAL/INSTITUTIONAL SOURCES, pg/J

Pollutant	Combustion source		
	Underfeed stoker, 4.2 GJ/hr input	Underfeed stoker, 2.8 GJ/hr input	Pulverized dry bottom, 123 GJ/hr input
Total benzene-soluble organics	3790	2840	2750
Benzo(a)pyrene	9.5	0.11	0.030
Pyrene	15.2	1.6	0.228
Benzo(e)pyrene	7.5	0.22	0.087
Perylene	1.5	ND	ND
Benzo(g,h,i)pyrene	4.3	ND	ND
Anthanthrene	0.27	ND	ND
Coronene	0.31	ND	ND
Anthracene	0.81	ND	ND
Phenanthrene	95	0.95	ND
Fluoranthene	36	3.0	7.60

ND - Not detected. Source: Reference 25.

4.1.5 Existing Emissions Data: Internal Combustion Reciprocating Engines

Several reference sources contain emissions data for gas- and oil-fueled stationary reciprocating engines.[14-16] Much of the data has been summarized in Reference 14. Criteria pollutant emissions data excerpted from these reference sources are summarized in Table 19. Data are for small- to medium-size units, up to 800 hp, of the type used in the commercial sector for pumping municipal water and sewage. Pollutants of major significance are NO_x and HC. The variability of the existing data for NO_x, HC, and CO emissions from gas-fired engines is less than 70 percent, and the data are considered adequate.

As shown in Table 19, data obtained for diesel-fueled engines, from Reference 14, indicate that particulate and HC emissions are seven to two times lower, respectively, than EPA emission factors. The severity factor for particulates, using the higher EPA value for calculation, is low, and the data base for particulates is adequate.

Particle size information is limited for diesel engines. One study did indicate that approximately 75 percent by weight of particulate emissions was less than 1 μm in size, and approximately 85 percent by weight was less than 3 μm. Thus, most of the particulate emissions can be considered to be fine particulates.

Data for primary sulfates are presented in Reference 14. This TRW study reported that for two tests of oil-fired engines, 1.0 and 1.1 percent of the fuel sulfur was converted to SO_3. Fuel sulfur conversion to particulate sulfate averaged 0.33 percent, based on five tests of emissions from oil-fired reciprocating engines. Assuming a fuel sulfur content of 0.24 percent and an average conversion to SO_3 of 1.0 percent, the SO_3 emission factor is 1.26 ng/J. Using this emission factor, the ambient severity factor for SO_3 emissions from oil-fired engines is 0.03. Emissions of SO_3 at assumed levels would not be significant. Emissions of SO_3 from gas-fired engines were not measured but are insignificant because of the low sulfur content of natural gas.

TABLE 19. SUMMARY OF CRITERIA POLLUTANT EMISSIONS DATA FOR SMALL TO MEDIUM SIZE STATIONARY RECIPROCATING ENGINES

Pollutant	Number of units	Mean emission factor (ng/J)	Vari-ability (%)	Ambient severity factor[a]	EPA emission factor (ng/J)	Data from reference 14 (ng/J)
Gas-fired IC engines						
Particulates	-	-	-	0.001	5.1[b]	-
SO_2	-	-	-	0.001	0.26	-
NO_x	14	1590	19	1.85	1390	-
HC	13	380	68	0.23	573	-
CO	11	280	65	0.008	176	-
Diesel-fueled IC engines						
Particulates	-	-	-	0.027	102	14
SO_2	-	-	-	0.019	403S[c]	101
NO_x	15	1360	24	16	1420	-
HC	15	320	28	0.19	115	-
CO	15	550	27	0.002	312	-

[a] The NO_x, HC and CO emission factors from the existing data, and the particulate and SO_x EPA emission factors and average fuel sulfur contents were used to calculate ambient severities. An average heat rate of 7,500 Btu/bhp-hr and an average unit size of 490 hp were used in the calculation.

[b] Assumed to be the same as for gas-fueled turbines.

[c] S = fuel sulfur content in percent.

- = Not measured.

Trace element and organic emissions data are also presented in Reference 14 for electricity generation distillate oil engines. It was concluded that the trace element emissions data base for distillate oil engines is adequate and that emissions of organics and POM are either environmentally insignficant or at levels too low to be detected. Mean POM emission factors and associated ambient severity factors for electricity generation distillate oil engines are shown in Table 20. Despite the conclusions drawn in Reference 14, no POM emission data exist for small- to medium-size internal combustion engines used in the commercial/institutional sector, and these engines should be tested.

TABLE 20. MEAN AMBIENT SEVERITY FACTORS FOR POM EMISSIONS FROM ELECTRICITY GENERATION DISTILLATE OIL ENGINES

Compound	Mean emission factor (pg/J)	MATE value[a] (mg/m^3)	Mean ambient severity factor
Naphthalene	43.7	50	< 0.0001
Methyl Naphthalene	130.6	230	< 0.0001
C_2 Substituted Naphthalene	198.2	230	< 0.0001
C_3 Substituted Naphthalene	128.6	230	< 0.0001
C_4 Substituted Naphthalene	33.3	230	< 0.0001
C_5 Substituted Naphthalene	11.0	230	< 0.0001
Biphenyl	5.8	1.0	0.0006
Methyl Biphenyl	21.0	1.0	0.0022
C_3 Biphenyl	1.5	1.0	0.0002
Dibenzothiophene	0.50	23	< 0.0001
Methyl Dibenzothiophene	0.071	23	< 0.0001
Phenanthrene/Anthracene	19.1	1.6	0.0013
Methyl Phenanthrene/Anthracene	36.0	30	0.0001
Dimethyl Phenanthrene/Anthracene	10.8	30	< 0.0001
Trimethyl Phenanthrene/Anthracene	2.0	30	< 0.0001
Ethyl Fluorene	2.2	90	< 0.0001

[a] MATE values are obtained from Reference 30.

Source: Reference 14, Table 54.

4.2 EMISSIONS DATA ACQUISITION

4.2.1 Selection of Test Facilities

The impact of emissions from commercial/institutional combustion sources may be more significant than is indicated by the relatively small amount of fuel used by this sector of the economy. This concern is based on the scarcity of existing emissions data and the general feeling that emissions, particularly organic emissions, may be higher than anticipated because of the lack of proper maintenance and operating practices within the commercial sector. Accordingly, several representative commercial/institutional combustion sources were selected for testing.

The choice of specific sites was based, to the extent possible, on the representativeness of the sites as determined by the important characteristics of systems within each source category. As discussed in Section 3, candidate test facilities (external combustion sources) should generally be smaller than 13 x 10^9 J/hr input capacity, with the exception of coal-fired pulverized boilers and some stokers that are available only in larger capacities. Unit size was also considered in the selection of internal combustion sources to reflect the sizes commonly found in the commercial/institutional sector. Other factors considered in the selection of test sites included burner and boiler type. Most testing was done at close to baseline conditions; no tests were conducted on systems that operated in an on/off mode or with system modulation. As noted in Section 3, information concerning combustion system age was generally not available, and age was not a major factor in the selection of test sites. The effect of age, however, was considered in the evaluation of the data from the sites tested in this program.

The adequacy of the existing data base and the potential significance of the air pollution impact caused by flue gas emissions were also considered. Thus, more coal- and wood-fired sites were tested than would be warranted by fuel consumption estimates because of the recognized high emissions from these sources and the lack of data adequately characterizing fine particulate, SO_3, and organic emissions from these sources. Overall, a total of 28 sources was selected for testing. These sources included two pulverized, dry bottom boilers and three stokers fired by bituminous coal, three anthracite stokers, and one wood-fired stoker. In addition, five residual oil, three distillate oil, and five natural gas boilers were selected for testing. The internal combustion sources tested were all reciprocating engines: four oil-fired, one natural gas-fired, and one dual-fired unit.

The rated output capacity, manufacturer, burner and boiler type, and pollution control method, as appropriate for the 28 sources tested, are presented in Tables 21 through 24. As can be seen from the tables, many units exceed the accepted maximum capacity of 13 x 10^9 J/hr for commercial external combustion sources and represent units used at institutions such as schools and hospitals. Although considerable effort was made to select small boilers, it was not always possible to do so, and several large institutional boilers were tested because of their availability during the testing phase of this program. Although reliable age data for reciprocating engines were not available, the four diesel-fired units tested were much older than the average age of 10 years estimated for industrial reciprocating engines.[14]

4.2.2 Field Testing

Field testing procedures were based on Level I environmental assessment methods. The SASS train was used to collect particulate, organic and trace metal samples. This train, shown in Figure 1, is a high volume (5 scfm) system design to extract particulates and gases from the flue gas stream, separate particulates into four size fractions, trap organics in an adsorbent, and collect volatile trace metals in liquid solutions. The high volume is required to collect adequate quantities of trace materials for subsequent laboratory analysis. All sample-contacting surfaces are type 316 stainless steel, Teflon, or glass.

In accordance with the program Procedures Manual[9]* the cyclones were not used at the gas- and oil-fired sources because of low concentrations of particulates and their characteristically small particle diameters for these fuels. In all tests, however, particulates were collected on Spectrograde® glass fiber filters in the heated oven. The sample stream was then cooled and the organic material collected by adsorption on XAD-2 resin (a styrene,

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*This Procedures Manual was developed specifically for this program and is not an approved IERL-RTP Procedures Manual.

TABLE 21. CHARACTERISTICS OF COMMERCIAL/INSTITUTIONAL GAS-FIRED EXTERNAL COMBUSTION SOURCES SELECTED FOR TESTING

Site No.	Manufacturer	Boiler type	Rated capacity[a] (GJ/hr)	Rated capacity[a] (MW)	Age as of 1979 (years)	Pollution control device
121	Babcock & Wilcox	Packaged watertube	132	37	6	No control device
122	Babcock & Wilcox	Packaged watertube	69	19	28	No control device
123	Babcock & Wilcox	Packaged watertube	79	22	16	No control device
333	E. Keeler	Packaged watertube	18	5.1	10	No control device
352	Union Iron Works	Packaged watertube	40	11	22	No control device

[a] Output capacity.

TABLE 22. CHARACTERISTICS OF COMMERCIAL/INSTITUTIONAL OIL-FIRED EXTERNAL COMBUSTION SOURCES SELECTED FOR TESTING

Site No.	Manufacturer	Fuel No.	Burner type	Boiler type	Rated capacity[a] (GJ/hr)	(MW)	Age as of 1979 (years)	Pollution control device
120	Babcock & Wilcox	4	Steam	Packaged watertube	132	37	4	No control device
124	Babcock & Wilcox	4	Steam	Watertube	69	19	28	No control device
138	Babcock & Wilcox	4	Steam	Watertube	74	21	16	No control device
337	North American	5	Air	Packaged watertube	18	4.9	21	No control device
346	Cleaner Brooks	6	Air	Packaged firetube	1.8	4.9	14	No control device
139	Trane-Murray	2	Air	Packaged watertube	37	10	5	No control device
140	Trane-Murray	2	Air	Packaged watertube	37	10	5	No control device
339	H.B. Smith	2	Pressure	Packaged cast iron	5.3	1.4	4	No control device

[a] Output capacity.

TABLE 23. CHARACTERISTICS OF COMMERCIAL/INSTITUTIONAL SOLID FUEL-FIRED EXTERNAL COMBUSTION SOURCES SELECTED FOR TESTING

Combustion source type	Site No.	Manufacturer	Rated capacity[a] (GJ/hr)	(MW)	Age as of 1979 (years)	Pollution control device
Bituminous, pulverized dry bottom boilers	321	Combustion Engineering	148	41	38	No control device
	343	Combustion Engineering	92	26	30	Multiclone followed by a wet scrubber; 99% efficiency
Bituminous stokers						
Underfeed	220	Will-Burt	2.3	0.63	20	No control device
Spreader	325	Riley-Stoker	26	7.1	12	Mechanical precipitator; 70% efficiency
Overfeed	342	E. Keeler	15	4.2	1	Mechanical precipitator; 70% efficiency
Anthracite stokers	320	E. Keeler	12	3.5	23	No control device
	344	E. Keeler	9.2	2.7	24	No control device
	345	E. Keeler	9.2	2.7	24	No control device
Wood stokers, underfeed	219	Will-Burt	2.3	0.63	20	No control device

[a] Output capacity.

TABLE 24. CHARACTERISTICS OF COMMERCIAL/INSTITUTIONAL INTERNAL COMBUSTION RECIPROCATING ENGINES SELECTED FOR TESTING

Site No.	Manufacturer	Fuel	Rated capacity		Age as of 1979 (years)	Pollution control device
			(hp)	(MW)		
329	Fairbanks Morse	Diesel	150	0.11	22	No control device
347	Fairbanks Morse	Diesel	640	0.48	20	No control device
348	Fairbanks Morse	Diesel	640	0.48	20	No control device
350	Fairbanks Morse	Diesel	600	0.45	20	No control device
349	Caterpillar	Natural gas	405	0.35	2	No control device
353[a]	Chicago Pneumatic Tool	Natural gas	670	0.5	5	No control device

[a] Dual-fired (approximately 5 percent oil thermal input).

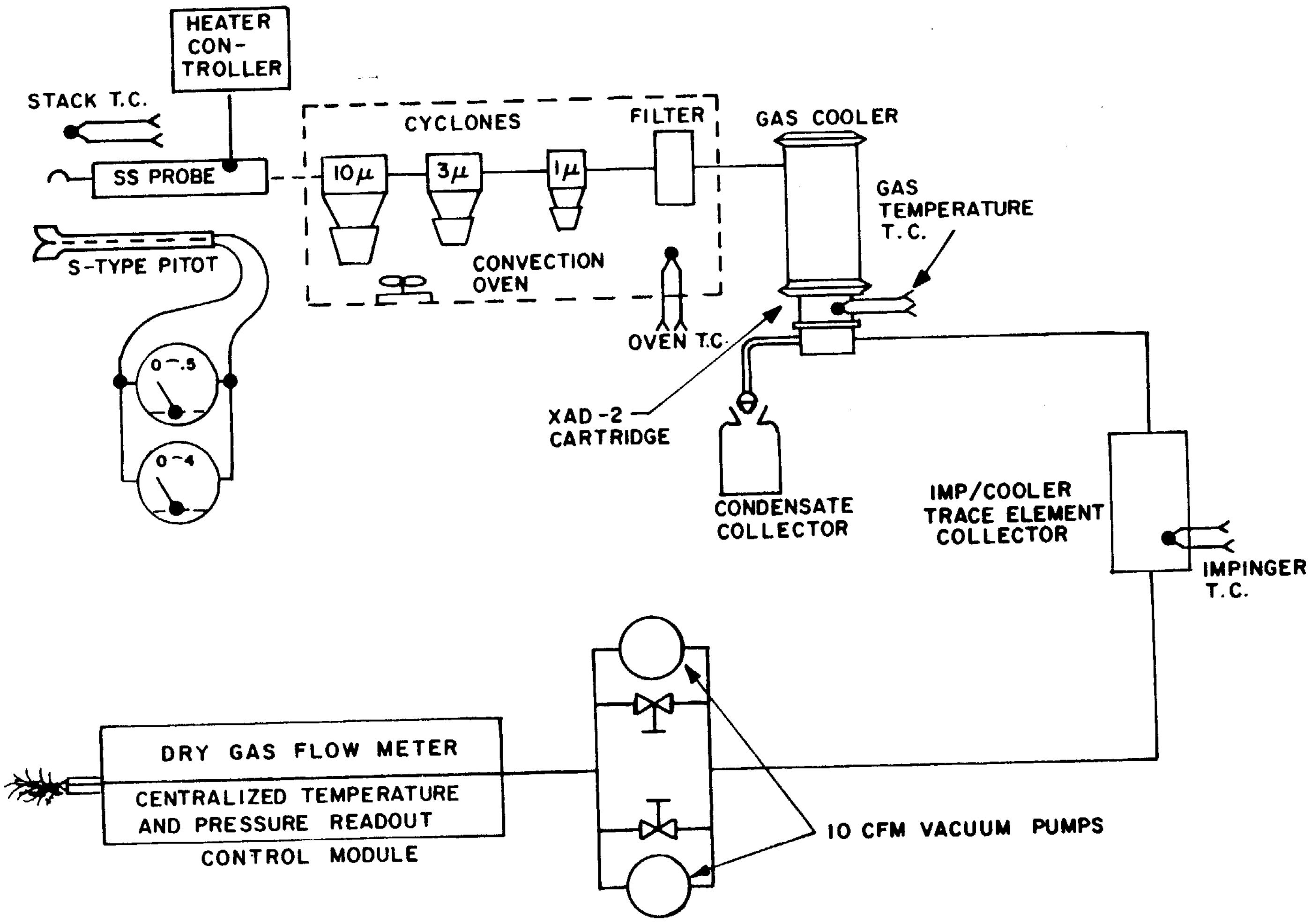


Figure 1. Schematic of Source Assessment Sampling System (SASS).

divinylbenzene copolymer). The gas then passed through an impinger containing hydrogen peroxide to collect oxidizable constituents. The second and third impingers, containing ammonium peroxydisulfate and silver nitrate, were used to collect volatile trace elements. A fourth impinger containing silica gel was used to remove the remaining moisture from the gas stream.

Samples of the flue gas were obtained at a single traverse point approximating the average flow rate of the flue gas, as determined by a multipoint traverse. Sampling time for the SASS train was from 4 to 6 hours as required to obtain a total sample volume of 30 cubic meters or greater. Sample recovery was carried out in a clean environment according to Level I procedures. All sample containers were precleaned and handled according to the Level I specifications.

Modified Level I field tests were conducted at the stack for 28 commercial/institutional combustion sources. The operating load, fuel feed rates, and percent excess air measured at the stack exit for the sites tested are presented in Table 25. Twenty-six of the sites were tested at energy input levels ranging from 65 to 100 percent of design capacity. The other two tests were conducted under significantly derated conditions: 41 percent of design capacity for a stoker unit burning wood (site 219) and a stoker unit burning bituminous coal (site 220). In general, excess air values measured at the flue gas exit were much higher than values consistent with good combustion. The high values were attributed to air leakage into the system at locations between the combustion chamber and stack.

Samples of the flue gas were also collected in gas sampling bags, using a stainless steel probe, condenser, and diaphragm pump, for onsite analyses of flue gas constituents. The gas in the bag was injected into a gas chromatograph through a heated gas sampling valve. Low molecular weight hydrocarbons were analyzed using a flame ionization detector, measuring the resulting peaks for retention times and areas and comparing these against a known series of C_1-C_6 n-alkane standards for qualitative and quantitative analysis. Carbon monoxide, CO_2, O_2, and N_2 were measured using a thermal conductivity detector and standard mixtures of these gases for calibration.

TABLE 25. OPERATING LOAD AND ENERGY INPUT RATES OF THE COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES TESTED

Combustion source type	Site No.	Operating load (GJ/hr)	Percent of base load	Energy input (GJ/hr)	Flue gas excess air (%)
<u>External combustion</u>					
Natural gas	121	106	80	133	30
	122	53	77	71	30
	123	53	67	71	32
	333	12	66	15	11
	352	34	85	45	205
Distillate oil	139	30	80	45	28
	140	30	80	41	42
	339	4.2	80	5	75
Residual oil	120	106	80	127	30
	124	46	67	61	50
	138	68	92	91	33
	337	12	65	17	190
	346	14	80	19	400
Bituminous, pulverized dry bottom	321	116	79	153	120
	343	87	94	116	51
Bituminous, stoker	220	0.94	41	1.5	105
	325	18	70	22	290
	342	15	100	19	59
Anthracite, stoker	320	12	100	25	260
	344	92 9.2?	100	21	425
	345	9.2	100	21	235
Wood, underfeed stoker	219	0.94	41	1.7	150
<u>Internal combustion</u>					
Natural gas, reciprocating engine	349	0.96	80	3.7	20
	353[a]	1.5	88	10.5	180
Distillate oil, reciprocating engine	329	0.37	100	1.3	180
	347	1.3	80	4.7	400
	348	1.3	80	4.7	390
	350	1.5	94	4.1	150

[a] Dual-fired.

Three coal-fired units were also sampled at the stack exit for SO_3 using the Controlled Condensation System (CCS), which is a modified Goksöyr-Ross procedure. The CCS sampling train consists of a quartz nozzle, a heated quartz probe liner, a heated quartz filter holder containing a quartz filter, a Pyrex modified Graham condenser, a series of impingers, a dry gas meter, and a leakless pump. The condenser is maintained at a temperature below the acid dewpoint by a heated circulating water bath, causing the SO_3 in the sample gas to condense as sulfuric acid.

Sampling of flue gas for NO_X was conducted either by EPA Method 7 (40 CFR 60, Appendix A, Method 7) or by chemiluminescence at several solid fuel-fired units and also at several internal combustion sites.

4.2.3 Laboratory Analysis Procedures

The procedures described in this section are designed to be an integral part of the phased environmental assessment approach and apply primarily to Level I. The purpose of this initial Level I phase is to obtain preliminary environmental assessment information, identify problem areas, and provide the basis for the prioritization of streams, components, and classes of materials for further testing by more stringent techniques and procedures. To accomplish this purpose the results of Level I sampling and analysis procedures should be quantitative within a factor of ±3. A detailed discussion of the approach along with the criteria used for method selection is given in the Methods and Procedures Manual[9] developed for this program. In addition, changes in methods and procedures have occurred during the course of this program to reflect experience, changing data needs, and EPA-directed Level I changes. A detailed list of these changes is provided in Volume III of this program series. Major changes include the following:

- The computation of inorganic emissions from gas- and oil-fired sites has been modified, based on the assumption that inorganic emissions are nil from gas-fired sites and that all inorganics from fuel oil combustion are emitted from the stack. Thus, inorganic emissions from oil-fired sites were calculated from analysis of the fuel.
- Organic emission from gas- and oil-fired sites were integrated values as a result of combining SASS fractions before analysis.

- For solid fuel-fired sites sampled after June 1978, the XAD-2 resin residue (after Parr bomb combustion) was combined with the composite (module condensate, HNO_3 module rinse, and H_2O_2 impinger) sample before analysis by Spark Source Mass Spectrography (SSMS) for inorganics.

- Atomic Absorption Spectrometry (AAS) analysis of the second and third impingers for Hg was conducted only if the Hg concentration in the fuel was >0.1 ppm and "real values" for Hg were obtained for the composite sample.

- AAS analysis of the second and third impingers for As and/or Sb was conducted only if SSMS analysis for these elements showed a concentration of >1 ppm in the fuel and "real values" for the composite sample.

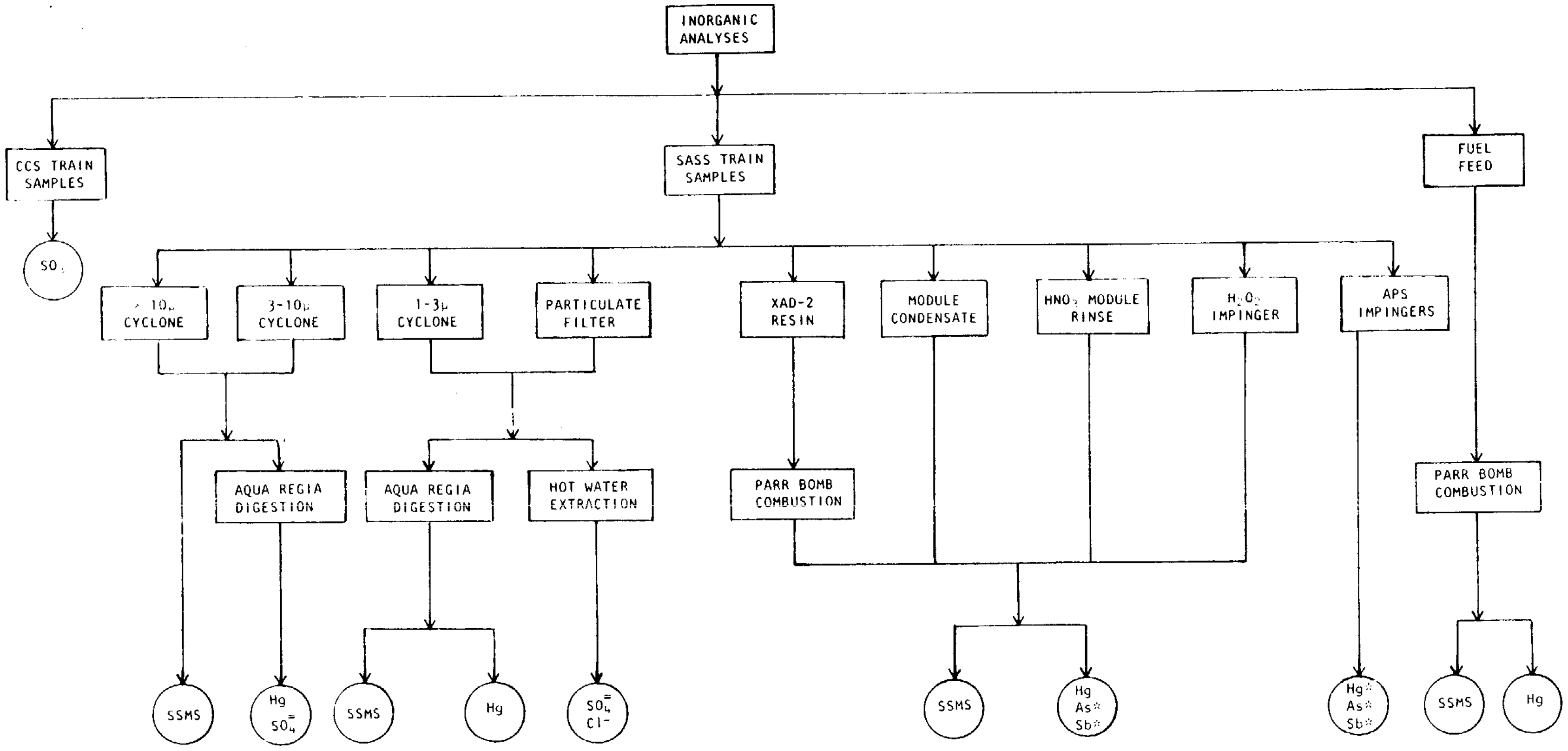
- The NO_x analysis procedure was changed to EPA Method 7 as a result of NO_x loss over time in the gas sampling bags.

4.2.3.1 Inorganic Analysis

As noted above, the inorganic analysis scheme was modified in the case of gas- and oil-fired sites, eliminating inorganic determinations for gas-fired sites and limiting inorganic determinations for oil-fired sites to an analysis of the fuel. In the case of the solid fuel-fired sites, the modified Level I analysis plan shown in Figure 2 was followed. The analytical scheme consisted of an elemental survey by SSMS for the determination of approximately 70 elements. Specific analyses by AAS were conducted for Hg and, when indicated by the results of the fuel analysis, for As and Sb. Particulate sulfate was determined turbidimetrically, chlorides were measured by specific ion electrode and/or ion chromatography, and SO_3 was determined by an acid-base titration.

Figure 2 also indicates the procedures followed to prepare samples for analysis. Particulate samples were digested with aqua regia before analysis. However, these samples were analyzed by SSMS without preparation when no glass fiber filter material was present. Samples for chloride analysis were extracted with hot water; this extract was also the preferred sample for sulfate analysis. Fuel feeds and XAD-2 resin were prepared by combustion in a Parr oxygen bomb to destroy the organic matrix. No preparative steps were necessary for the other inorganic samples.

Brief descriptions of the analytical techniques used for inorganic characterizations are provided below.



*Analysis dependent on certain criteria.

Figure 2. Modified Level I inorganic analysis plan for commercial/institutional solid fuel-fired combustion sources.

- SSMS - SSMS is used in the laboratory to perform a semi-quantitative elemental survey analysis on all types of Level I samples. The analysis is performed using a JEOL Analytical Instruments, Inc., Model JMS-01BM-2 Mass Spectrograph. The JMS-01BM-2 is a high resolution, double-focusing mass spectrometer with Mattauch-Herzog ion optics and ion sensitive photoplate detection. The instrument is specially designed to carry out high sensitivity trace element analysis of metals, powders, or semiconductor type materials using an RF spark ion source. Elemental analysis by SSMS involves the incorporation of a sample aliquot into two conducting electrodes that are decomposed and subsequently analyzed by a mass determination using a double-focusing mass spectrometer. Decomposition of the sample electrodes is accomplished by applying a radio frequency (~1 MHz) potential of about 4 kV, which induces an electrical discharge in the form of a spark plasma. Because of the high energy associated with the discharge, the spark plasma created is composed primarily of elemental species. The positively charged ions contained in the plasma are accelerated and formed into an ion beam by a high potential electric field (~30 kV). The beam is then energy-focused and momentum-dispersed to produce a mass spectrum that is recorded by an ion-sensitive photoplate.

  SSMS can be used to detect elemental species contained in the sample electrodes at levels down to 10^{-9} grams. Although the sensitivity varies somewhat, depending on the element of interest and the sample type, practically all elements in the periodic table can be detected. Using photoplate detection, all elements having masses in the range 6 to 240 can be detected simultaneously. Concentration data are derived from the intensities (optical density) of the mass spectral lines. There are several methods for determining concentration data from photoplate spectral line densities. The methods vary widely in terms of their complexity and corresponding precision and accuracy of the results. The photoplate interpretation procedures followed for this program and for Level I survey work in general are designed to yield concentration data accurate to within a factor of 2 for 70 elements.

- Mercury - Cold Vapor - The cold vapor mercury analysis is based on the reduction of mercury species in acid solution with stannous chloride and the subsequent sparging of elemental mercury, with nitrogen, through a quartz cell where its absorption at 253.7 nm is monitored.

- Arsenic - Hydride Evolution - This procedure entails the reduction and conversion of arsenic to its hydride in acid solution with either stannous chloride and metallic zinc or sodium borohydride. The volatile hydride is swept from the reaction vessel, in a stream of argon, into an argon-hydrogen flame in an AAS. There, the hydride is decomposed, and the arsenic concentration is monitored at its resonance wavelength, 193.7 nm. Excess hydrogen peroxide and nitric acid present in certain Level I samples interfere with the analysis and must be removed prior to the addition of either the zinc slurry or sodium borohydride used to generate the arsenic hydride.

- Antimony - Hydride Evolution - Antimony-containing compounds are decomposed by adding sulfuric and nitric acids and evapoparting the sample to fumes of SO_3. The antimony liberated is subsequently reacted with potassium iodide and stannous chloride, and finally with sodium borohydride to form stibine. The stibine is then removed from solution by aeration and swept by a flow of nitrogen into a hydrogen diffusion flame in an AAS. The gas sample absorption is measured at 217.6 nm. Because the stibine is freed from the original sample matrix, interferences in the flame are minimized.

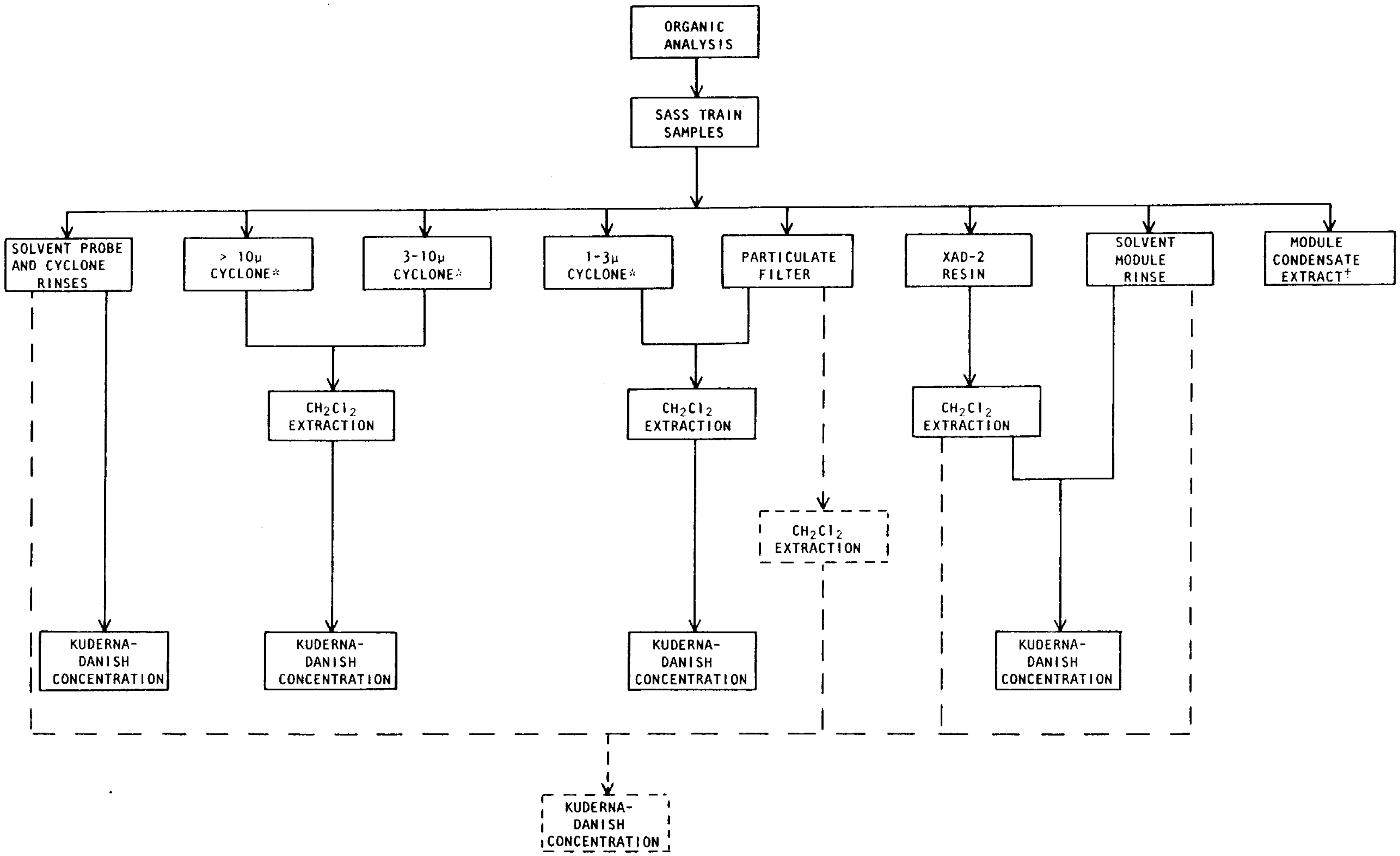
- Sulfate - Turbidimetric - The basis of the analysis is the formation of a barium sulfate precipitate in a hydrochloric acid medium with barium chloride so as to form barium sulfate crystals of uniform size. The absorbance of the barium sulfate suspension is measured by a transmission photometer, and the sulfate ion concentration is determined by comparing the reading with a standard curve.

- Chloride - Specific Ion Electrode and Ion Chromatography - Chloride is determined potentiometrically using a solid-state selective ion chloride electrode in conjunction with a double junction reference electrode and a pH meter having an expanded millivolt scale. Ion chromatography was used to check the results of the specific ion electrode determinations, and results were generally in excellent agreement.

- SO_3 - Controlled Condensation - The SO_3 concentration of the Goksöyr-Ross sampling train condenser coil rinse is determined by an acid-base titration against 0.02N sodium hydroxide that has been standardized against primary standard potassium acid phthalate.

4.2.3.2 Organic Analysis

An overview of the SASS train samples collected from commercial/institutional sources for organic analysis is shown in Figure 3. The sample preparation procedures and appropriate sample combination schemes are also shown in the figure. Organic liquids required no preparation; however, aqueous liquids and solid samples were extracted with methylene chloride to separate the organic and inorganic portions before analysis. In the case of



*SASS cyclones used at solid fuel-fired sites only.

†CH_2Cl_2 extraction performed in field; analyses performed on unconcentrated extract.

Figure 3. Modified Level I organic sample preparation scheme for commercial/institutional sources. (Dashed lines represent combination of samples from gas- and oil-fired sites.)

gas- and oil-fired sites, the solvent rinses of SASS train components were combined with the solvent extracts of the XAD-2 resin and particulate filters for concentration into one organic sample for analysis.

The modified Level I organic analysis methodology and decision criteria used for organic characterization of commercial/institutional sources are presented in Figure 4. All samples were first concentrated in Kuderna-Danish evaporators to 10-ml volumes. (If material dropped out of solution during concentration, the extract was restored to a convenient volume large enough for the material to redissolve.) Two 1-ml aliquots were taken from each concentrate for the following analyses:

- Total chromatographable organic material (GC-TCO) and GC/MS analysis for POM.
- Gravimetric determination of nonvolatile organic material and an infrared (IR) analysis on the residue from the gravimetric determination.

The data provided by performing the TCO and the gravimetric analyses were used to make the decision as to the analysis path to be followed for all other determinations. The TCO analysis provided quantitative information on the bulk amount of semivolatile organic material in the boiling range of the C_7 to C_{16} alkanes — 90°C to 300°C. The gravimetric analysis provided quantitative results on the amount of nonvolatile organics in the sample. These two values combined give an estimate of the total organic content of the sample. Whenever the total organic content of the sample was equivalent to a stack concentration of 500 $\mu g/m^3$ or less, the organic analysis was terminated. Whenever the value was greater than 500 $\mu g/m^3$ stack concentration, the direction of the analyses depended on the TCO results.

If the TCO was less than 10 percent of the total organic material, the analytical pathway labeled "Method 2" in Figure 4 was followed. A suitably sized sample aliquot was taken for liquid chromatographic fractionation, evaporated to dryness, and transferred to an LC column. Each separated fraction was subsequently subjected to gravimetric and infrared analyses. If the TCO was greater than 10 percent of the total organics, an aliquot for LC was prepared by solvent exchange to preserve the volatile species. In this

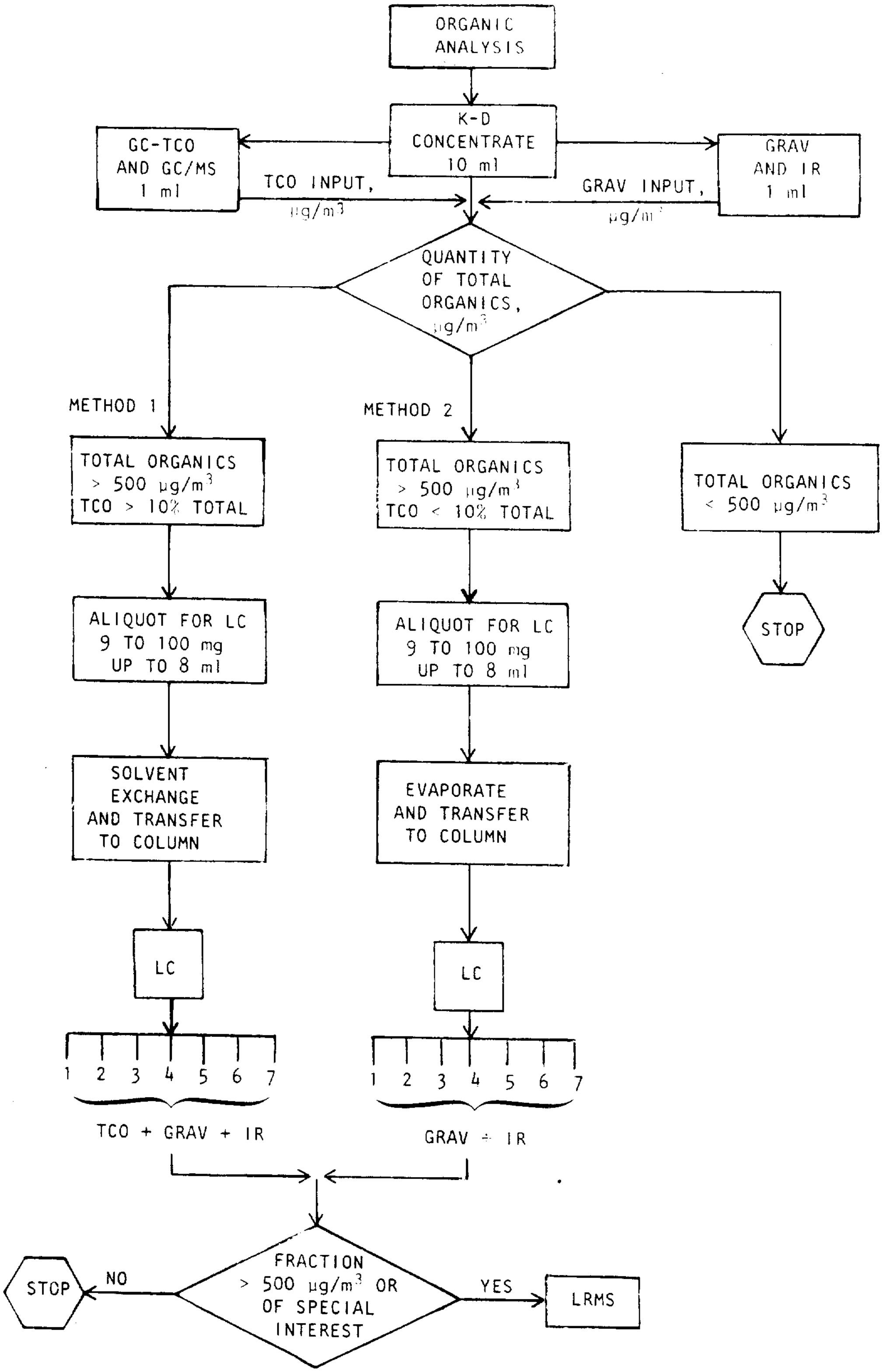


Figure 4. Modified Level I organic analysis plan for commercial/institutional sources.

"Method 1" procedure, each fraction separated still underwent gravimetric and infrared analyses; however, in addition, these LC fractions were also analyzed for TCO.

The GC-TCO analysis has been used to obtain information on the quantity of material boiling within discrete ranges corresponding to the boiling points of the n-alkanes C_7 through C_{16} as well as on the total amount of material in the overall n-alkane boiling range. Materials were classified solely on the basis of their retention time relative to the n-alkane and were quantitated as n-alkanes. Therefore, any compounds containing oxygen, nitrogen, sulfur, or halogens would also be reported as alkanes.

The infrared analyses provide information on the major functional groups (i.e., chemical compound classes) present in a sample. Data obtained by the GC-TCO and IR analyses are interrelated: many compounds detected in the GC analysis are too volatile to remain when the sample is evaporated for IR analysis; many compounds identified in the IR analysis have volatilities too low to be detected by the GC-TCO procedure. In a similar manner, the results of GC-TCO analyses of the LC fractions complement the IR analyses of these samples.

Fractions that contained more than 15 mg of material or which were of special interest were analyzed by low resolution mass spectroscopy (LRMS). LRMS is an instrumental technique that may provide molecular weights and compound identification on a "most probable" basis for samples of low complexity. In Level I analysis, it is used to supplement the compound classification derived from IR spectra.

Brief descriptions of the analytical techniques used in conducting the Level I organic analysis and the GC/MS analysis for POM are presented below.

- Extraction of Aqueous Samples - These liquid/liquid extractions were performed with standard separatory funnels. Whenever necessary, the pH of the sample was adjusted to neutral with a saturated solution of either sodium bicarbonate or ammonium chloride. The sample was extracted three times with a volume of high-purity methylene chloride equal to approximately 10 percent of the sample volume. The volume of the resulting extract was measured, dried with anhydrous sodium sulfate, and concentrated to 10 ml.

- Extraction of Solid Samples - The particulate filters, cyclone catches, and XAD-2 resin samples from the SASS train were extracted in appropriately sized Soxhlet extractors. Each sample was placed in a glass thimble and extracted for 24 hours with Distilled-in-Glass® or Nanograde® purity methylene chloride. The resulting extracts were measured, dried, and concentrated.

- Concentration of Organics - The solvent extracts of solid and liquid samples and the solvent rinses of sampling hardware were concentrated in K-D evaporators. Heat provided by a steam bath was sufficient to volatilize the solvents with minimal loss of other organic components. Samples were concentrated to a volume between 5 and 10 ml, allowed to cool, transferred to a volumetric flask, and diluted to a final volume of 10 ml with methylene chloride.

- Gravimetric Determination - The weight of nonvolatile organic species was determined on the concentrates obtained from the K-D concentration of solvent extract and rinse samples. The samples were transferred to tared aluminum weighing dishes, evaporated at ambient temperature, and stored in a desiccator to constant weight. Weights of organic residues as small as 0.1 mg were measured.

- Infrared Analysis - IR analysis was used to determine the functional groups in an organic sample or LC fraction of a partitioned sample. The interpreted spectra provide information on functionality (e.g., carbonyl, aromatic hydrocarbon, alcohol, amine, aliphatic hydrocarbon, halogenated organic, etc.). Compound identification is possible only when that compound is known to be present as a dominant constituent in the sample.

  The minimum sample amount required for this analysis is 0.5 mg. A compound must be present in the sample at 5 to 10 percent (w/w) at least for the characteristic functional groups of a compound to appear sufficiently strong for interpretation. Organic solvents, water, and some inorganic materials cause interferences. Water, in particular, decreases the resolution and sensitivity of the analysis.

  The initial organic sample concentrate or LC fraction, after evaporation, was either (1) taken up in a small amount of carbon tetrachloride or methylene chloride and transferred to a NaCl window or (2) mixed with powdered KBr, ground to a fine consistency, and then pressed into a pellet. A grating IR spectrophotometer was used to scan the sample in the IR region from 2.5 to 15 microns.

- Total Chromatographable Organic Material Analysis - GC was used to determine the quantity of low boiling hydrocarbons (BP between 90°C and 300°C) in the K-D concentrates of all solvent rinses and organic extracts and in LC fractions 1 through 7 (when the volatile organics were greater than 10 percent of the total organics in the unfractionated sample). Data were used to first determine the total quantity of the lower boiling hydrocarbons in the sample. Whenever this total of C_7 to C_{16} hydrocarbons exceeded a stack concentration of 75 $\mu g/m^3$, the TCO results were reported as quantities in each of the C_7 to C_{16} boiling point ranges rather than as a total.

The extent of compound identification was limited to representing all materials as normal alkanes based on comparison of boiling points. The analysis was semiquantitative because only one hydrocarbon, n-decane, was used for calibration. The differences in instrument response, or sensitivity, to other alkanes were well within the desired accuracy limits for Level I analysis and are not taken into consideration in data interpretation.

- Liquid Chromatographic Separation - This procedure was designed to separate samples into eight reasonably distinct classes of compounds and was applied to all organic samples that contained a minimum of 500 $\mu g/m^3$ of combined volatile (TCO) and nonvolatile (gravimetric) organics. A sample weighing from 9 to 100 mg was placed on a silica gel liquid chromatographic column, and a series of eight eluents of sequentially increasing polarity was used to separate the sample into eight fractions for further analyses. Because the use of HCl in the final eluent results in partial degradation of the column material, data were derived from only the first seven fractions.

Two distinct methods were used to prepare samples for LC fractionation and subsequent analysis. The selection of "Method 1" or "Method 2" (Figure 4) was based on the results of gravimetric and TCO determinations on the concentrated organic sample. Method 1 was used whenever the volatile organic content determined by the TCO analysis was greater than 10 percent of the total. Method 2 was used whenever the TCO was low — less than 10 percent of the total.

In Method 1, the low boiling components must be preserved for LC separation and subsequent analysis. This requires a solvent exchange step to transfer the sample from methylene chloride to the nonpolar solvent hexane before placement on the column. In Method 2, where there are few volatile components, a simple, direct solvent evaporation step is sufficient to prepare the sample for fractionation.

Gravimetric and IR analyses were performed on the first seven fractions of all LC separations. In addition, whenever Method 1 was used, a TCO analysis was also performed on each of the seven fractions for information on the mass and types of volatile compounds present in each fraction. These data supplemented the gravimetric and infrared analyses performed on all fractions.

- Low Resolution Mass Spectroscopy - This procedure is a survey analysis used to determine compound types in an organic sample or in an LC fraction of a sample. The analyst is specifically searching for hazardous compounds or compounds that may be generally considered toxic; e.g., aromatic hydrocarbons and chlorinated organics. Analysis using different sample ionizing parameters results in molecular weight data that, combined with IR and sample source data, can provide specific compound identifications on a "most probable" basis.

  The mass spectrometer (MS) used in this procedure has sufficient sensitivity such that 1 nanogram or less presented to the ionizing chamber results in a full spectrum with a signal ratio of 10:1. A dynamic range of 250,000 is achievable. The detection limit for a specific compound related to the size of an air sample or liquid sample varies widely depending on the types and quantities of the species in the sample. This is due to interfering effects in the spectrum caused by multiple compounds. The impact of this interference is reduced by lowering the ionization voltage to produce spectra containing relatively more intense molecular ions.

  Solid samples are placed in a sample cup or capillary for introduction through the direct insertion probe. More volatile samples are weighed into a cuvette for introduction through a batch or liquid inlet system. The probe or cuvette is temperature programmed from ambient temperature to 300°C. Periodic MS scans are taken with a 70 eV ionizing voltage as the sample is volatilized during the program. A lower ionizing voltage range (10 to 15 eV) can be used at the discretion of the operator if the 70 eV data are complex. Spectra are interpreted using reference compound spectral libraries, IR data, and other chemical information available on the sample. The results of LRMS analysis give qualitative information on compound types, homologous series and, in some cases, identification of specific compounds. This information is then used to assess the hazardous nature of the sample.

- Gas Chromatography/Mass Spectrometry Analysis for POM - This is a combined GC/MS method for qualitative and quantitative POM determinations. Microliter quantities of concentrated sample extracts are used for this analysis.

  Microliter-size samples are injected onto a gas chromatographic column and are separated by the differences in the retention characteristics between the sample components and the column material. As the components elute from the column, they are transported through an instrument interface to the mass spectrometer, which is being operated in a Total Ion Monitoring (TIM) mode.

In the MS, the various compounds are ionized, and all ion fragments in the mass range of 40 to 400 amu are monitored. The resulting mass spectra are stored by the computerized data system. Depending on the desired scope of the analysis, all compounds eluting from the GCA in detectable quantities could be identified, including aromatic compounds containing heteroatoms. The computer is used to search the stored spectra for the specific mass fragments shown in Table 26.

TABLE 26. MASS TO CHARGE (m/e) VALUES MONITORED[a]

128	180	242
154	184	252
162[b]	192	256
166	202	278
178	216	300
179	228	302

[a] Mass to charge values have units in (gm/gm mole)/(electron/molecule).

[b] Internal standard is chloronaphthalene.

The spectra of POM are quite distinctive because they yield very strong molecular ions with little fragmentation. Using molecular ions to find POM in a mixture involves reconstructing the GC trace from the stored data using only a single mass to charge (m/e) value. Any inflection in this mass chromatogram indicates the possibility of a POM of that molecular weight. The spectrum is then displayed, and the operator judges if the spectrum is consistent with a POM. The GC retention time and the spectrum are used to make this identification although it is often difficult to confirm which isomer is causing a peak without standards for the specific material.

Using this technique, a large number of POM can be screened in a short period of time, and good identification of POM type is possible. More time is required for exact identification. Table 27 lists POM that are sought in all samples; any POM with a molecular weight on this list will be determined. If other POM with different molecular weights are desired, all that is needed for their identification is the molecular weight and a relative retention time or a standard. During the search of the data for POM compounds, non-POM compounds may interfere, especially if they coelute with a POM. Computer data interaction techniques, such as ion mapping, keep these interferences to a minimum. If a POM is confirmed, the peak is quantitated using an internal standardization method.

TABLE 27. MINIMUM LIST OF POM MONITORED

Compound name	Molecular weight	MATE value, air ($\mu g/m^3$)
Naphthalene	128	5.0×10^4
Biphenyl	154	1.0×10^3
Fluorene	166	1.4×10^4
Phenanthrene	178	1.59×10^3
Anthracene	178	5.6×10^4
Benzoquinoline	179	N
Acridine	179	9.0×10^4
9,10-Dihydro-phenanthrene	180	N
9,10-Dihydro-anthracene	180	N
2-Methyl-fluorene	180	N
1-Methyl-fluorene	180	N
9-Methyl-fluorene	180	N
Dibenzothiophene	182	2.3×10^4
3-Methyl-phenanthrene	192	3.0×10^4
2-Methyl-phenanthrene	192	3.0×10^4
2-Methyl-anthracene	192	3.0×10^4
Ethyl fluorene	195	N
Methyl Dibenzothiophene	196	N
Fluoranthene	202	9.0×10^4
Pyrene	202	2.3×10^5
Dimethyl phenanthrenes	206	N
Benzo(a)fluorene or 1,2-benzofluorene	216	N
Benzo(b)fluorene or 2,3-benzofluorene	216	N
Benzo(c)fluorene or 3,4-benzofluorene	216	N
2-Methyl-fluoranthene	216	N
4-Methyl-pyrene	216	N
3-Methyl-pyrene	216	N
1-Methyl-pyrene	216	N
Trimethyl phenanthrenes	220	N

(continued)

TABLE 27 (continued)

Compound name	Molecular weight	MATE value, air (μg/m^3)
Benzo(c)phenanthrene	228	2.73×10^4
Benzo(ghi)fluoranthene	228	N
Benzo(a)anthracene	228	4.5×10^1
Chrysene	228	2.2×10^3
Triphenylene (9,10 Benzo Phenanthrene)	228	N
4-Methyl-benzo(a)anthracene	242	N
1-Methyl-chrysene	242	1.79×10^3
6-Methyl-chrysene	242	1.79×10^3
Benzo(f)fluoranthene	252	N
Benzo(k)fluoranthene	252	1.63×10^3
Benzo(b)fluoranthene	252	9.0×10^2
Benzo(a)pyrene	252	2.0×10^{-2}
Benzo(e)pyrene	252	3.04×10^3
Perylene	252	N
Benzo(c)tetraphene	256	N
7,12-Dimethyl-benzo(a)anthracene	256	2.6×10^{-1}
9,10-Dimethyl-benzo(a)anthracene	256	2.96×10^1
1,2,3,4-Dibenzanthracene	278	1.0×10^4
2,3,6,7-Dibenzanthracene	278	N
Benzo(b)chrysene	278	N
Picene	278	2.5×10^3
Coronene	300	N
Benzo(ghi)perylene	302	5.43×10^2
1,2,3,4-Dibenzpyrene	302	N
1,2,4,5-Dibenzpyrene	302	N
Alkyl substituted naphthalenes	-	2.0×10^5
Alkyl substituted biphenyl	-	N

N = Not available.

> The GC/MS sensitivity varies with several parameters including the type of compound, instrument internal cleanliness, resolution of closely eluting peaks, etc. Under "everyday" operating conditions, 20 nanograms (ng) eluting in a peak about 5 seconds wide yield an MS signal with a usable signal-to-noise ratio. Typically, this represents at least 100 μg of any single POM compound in a concentrated extract of a sample.

4.2.3.3 Detection Limits

A minimum flue gas sampling volume of 30 m^3 is required for all SASS runs to ensure that all pollutant species of interest, both inorganic and organic compounds, can be detected at levels that represent the lower limits of environmental concern. A detailed discussion of detection limits of analysis procedures is presented in the program Methods and Procedures Manual.[9]

4.2.4 Test Results

4.2.4.1 Field Measurement Results

Oxygen concentration data and particulate, NO_x, CO, and hydrocarbon emissions data for the tests conducted are shown in Table 28. The C_1-C_6 gaseous hydrocarbon measurements were conducted in the field, but the C_7-C_{16} and the $> C_{16}$ hydrocarbon emissions were determined in the laboratory. These laboratory determinations are included in Table 28 to facilitate comparison with C_1-C_6 hydrocarbon emissions and calculation of total hydrocarbon emissions. Particulate emission data represent uncontrolled emissions. Data from the three bituminous coal-fired units that were controlled have been adjusted to account for the reported control efficiency. Control efficiencies for these three units (Sites 325, 342 and 343) were 70, 70 and 99 percent, respectively. Only a limited number of NO_x and CO emission measurements were made because of the general adequacy of the existing emissions data base for these pollutants. Sulfur dioxide emission data were not obtained and are not shown in Table 28. Emissions, however, can be computed from the fuel sulfur content.

The data reduction procedures for converting emission concentrations (ppm or mg/m^3) to emission factors (ng/J) are presented in Appendix B. The test results presented in Table 28 will be discussed in detail in Section 4.3.

TABLE 28. FLUE GAS EMISSIONS OF PARTICULATES, NO_x, CO, AND HC FROM THE COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES TESTED

Combustion source type	Site No.	O_2 (%)	Particulates[a] (ng/J)	NO_x (ng/J)	CO (ng/J)	Hydrocarbons			
						C_1-C_6 (ng/J)	C_7-C_{16} (ng/J)	>C_{16} (ng/J)	Total (ng/J)
Gas-fired Boilers	121	5.6	<0.001	-	-	-	0.03	0.07	>0.1
	122	5.6	<0.001	-	-	-	0.03	0.14	>0.2
	123	6.0	<0.001	-	-	-	0.06	0.04	>0.1
	333	2.2	0.17	26	-	9.1	0.22	0.7	10.0
	352	14.5	1.9	44	9	0.2	0.08	0.24	0.5
Residual Oil-fired Boilers	120	5.1	8.9	-	-	-	0.16	0.5	>0.7
	124	7.0	6.2	-	-	9.7	0.24	0.33	10.1
	138	6.1	5.6	-	-	0.7	0.02	0.18	0.9
	337	13.8	34	-	49	3.5	1.3	2.2	7.0
	346	17.0	8.0	-	3.2	<0.1	1.3	4.8	6.1
Distillate Oil-fired Boilers	139	5.3	3.7	-	-	0.7	0.17	0.43	1.3
	140	7.0	4.0	-	-	0.25	0.02	0.001	0.3
	339	9.2	16	-	68	1.4	1.4	6.5	9.3
Bituminous, Pulv. Dry Bottom Boilers	321	11.6	2560	248	<60	1.3	0.46	0.66	2.4
	343	7.0	1470	280	-	0.3	0.09	1.6	2.0
Bituminous Stokers	220	12.4	12	-	-	-	0.3	4.1	>4.4
	325	15.5	1210	259	-	1.0	2.2	2.6	5.8
	342	6.9	350	189	0.6	0.03	0.4	9	9.4
Anthracite Stokers	320	15.8	535	-	-	<0.1	0.17	6.3	6.5
	344	16.9	502	-	-	3.0	0.54	2.8	6.3
	345	14.8	171	-	-	0.6	0.09	1.1	1.8
Wood, Underfeed Stokers	219	12.4	39	8	<20	-	34.7	46.2	>81.0
Internal Combustion Reciprocating Engines, Oil-fired	329	13.3	68	950	-	2.8	52	90.0	145
	347	17.0	25	1243	167	19.8	8.5	75.4	104
	348	16.7	14	1056	-	6.8	4.7	62.4	74
	350	13.0	59	-	170	626	16.9	110	754
Internal Combustion Reciprocating Engines, Gas-fired	349	3.8	0.1	765	450	4.5	0.1	0.6	5
	353[b]	13.8	10	-	590	203	17.6	21.4	242

[a] Uncontrolled particulate emissions.

[b] Dual-fired engine.

- =Not analyzed.

4.2.4.2 Laboratory Analysis Results

This section presents results of laboratory analyses of samples collected at the combustion sources tested. The analytical methodology used was described in Section 4.2.3.

Inorganic Analysis Results--

Trace element data, obtained by SSMS analysis, for each of the sites tested, are contained in Appendix C. These tabulated results are presented for up to 65 elements for each section of the SASS train analyzed and are summed to provide a total value and an emission concentration. SSMS results of oil and solid fuel analyses, as well as calculated elemental emission concentrations are also presented. These calculations were based on the assumption that the total elemental content of the fuel is emitted with the flue gas. Trace element analyses were not conducted for the natural gas-fired sites. A discussion of the trace element data will be presented in Section 4.3.

A summary of the data from the specific inorganic analyses conducted is presented in Table 29. Data are shown for emission concentrations of Hg, As, and Sb from oil- and coal-fired sources as determined by AAS. The concentrations of As and Sb found in the second and third impingers of the SASS train were generally less than 10 percent of the total SASS train concentrations determined by SSMS. A modified Goksöyr-Ross procedure was used to determine SO_3 concentrations; the procedure for the determinations of sulfate ions has been described in Section 4.2.3. A key to the sample codes is provided in Figure 5.

Organic Analysis Results--

Total Organic Emissions - Tables 30, 31, and 32, respectively, represent summaries of organic emissions from gas-, oil-, and solid fuel-fired external combustion sources and from internal combustion reciprocating engines used in the commercial/institutional sector. The data are quantitative and are grouped into three general categories consistent with the procedures used for analysis. These categories are:

- gaseous - compounds boiling below 90°C, C_1-C_6,
- volatile - compounds boiling between 90°C and 300°C, C_7-C_{16}, and
- nonvolatile - compounds boiling above 300°C, > C_{16}.

TABLE 29. SUMMARY OF RESULTS OF SPECIFIC INORGANIC ANALYSES FOR THE COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES TESTED

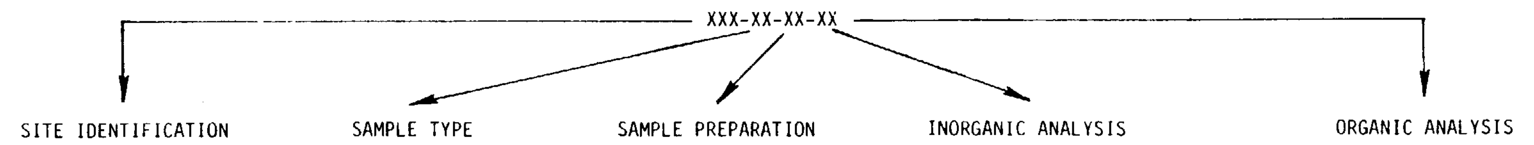
Source category	Site No.	Sample	Emission concentrations ($\mu g/m^3$)				
			Hg	$SO_4^{=}$[a]	SO_3[b]	As[c]	Sb[c]
Distillate Oil-fired Boilers and Engines	140	Fuel	4.8	-	-	-	-
	329	Fuel	3.3	-	-	-	-
	339	Fuel	<3.9	-	-	-	-
	347	Fuel	0.85	-	-	-	-
	348	Fuel	1.1	-	-	-	-
	350	Fuel	2.0	-	-	-	-
Residual Oil-fired Boilers	120	Flue gas	0.52	<100	-	-	-
	124	Flue gas	0.46	<100	-	-	-
	138	Fuel	6.7	-	-	-	-
	337	Fuel	3.6	-	-	-	-
	346	Fuel	3.7	-	-	-	-
Bituminous, Pulverized Dry Bottom Boilers	321	Flue gas	2.99	5,200	1,900	-	-
	343	Flue gas	1.15	3,200	-	2.0	0.64
Bituminous Stokers	220	Flue gas	0.34	2,675	-	-	-
	325	Flue gas	0.66	8,600	13,400	-	-
	342	Flue gas	16.2	4,350	-	0.9	0.63
Anthracite Stokers	320	Flue gas	3.4	4,700	18,600	-	-
	344	Flue gas	1.1	42,000	-	3.0	<0.3
	345	Flue gas	3.0	26,000	-	3.0	<0.7
Wood Stokers	219	Flue gas	0.14	6,244	-	-	-

[a] Particulate sulfate.

[b] Flue gas measurement by controlled condensation procedure.

[c] Measured by AAS; values represent emissions found in the second and third impingers of the SASS train.

- = Not measured.



SITE IDENTIFICATION

Consecutively numbered by sampling team:

100-199 - TRW West Coast
200-299 - TRW East Coast
300-399 - GCA

SAMPLE TYPE

Codes and corresponding sample types are as follows:

CF - Fuel fired (coal)
FF - Fuel feed (oil)
WF - Fuel fired (wood)
PR - Solvent probe/ cyclone rinse
XR - XAD-2 resin
MR - Solvent XAD-2 module rinse
XM - XR extract plus MR
CD - Condensate from XAD-2 module
HM - HNO_3 XAD-2 module rinse
HI - H_2O_2 impinger
CH - CD plus HM plus HI
CHX - CH + XR
AI - APS impingers
PF - Particulate filter(s)
IC - 1-3μ cyclone
FC - PF plus IC
3C - 3-10μ cyclone
10C - > 10μ cyclone
CC - 3C plus 10C

SAMPLE PREPARATION

Codes and corresponding preparation steps are as follows:

O - No preparation
LE - Liquid/liquid extraction
SE - Soxhlet extraction
KD - K-D concentration
A - Acidified aliquot
B - Basified aliquot
PB - Parr bomb combustion
HW - Hot water extraction
AR - Aqua regia extraction

INORGANIC ANALYSIS

Codes and corresponding procedures are as follows:

SS - SSMS
AAS - Hg, As, Sb
SO_4 - $SO_4^=$
NO_3 - NO_3^-
CF - Cl^-, F^-

ORGANIC ANALYSIS

Codes and corresponding procedures are as follows:

First Level	Second Level
GC - C_7-C_{16}	Resulting LC fractions are numbered in order 1-7 for:
GI - Grav., IR	GC - C_7-C_{16} GC
GM - GC/MS	GI - Grav., IR
LC - LC separation	MS - LRMS

Figure 5. Sample identification and coding for commercial/institutional sources.

TABLE 30. TOTAL ORGANIC EMISSIONS FROM THE GAS- AND OIL-FIRED COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES TESTED

Organics	Gas-fired boilers					Distillate oil-fired boilers			Residual oil-fired boilers				
	Site 121	Site 122	Site 123	Site 333	Site 352	Site 139	Site 140	Site 339	Site 120	Site 124	Site 138	Site 337	Site 346
Gaseous Organics, Field ($\mu g/m^3$)													
C_1	-	-	-	31,540	<70	2000	500	850	-	9,360	2060	600	<10
C_2	-	-	-	3,690	<125	<120	<100	3,280	-	17,500	<440	750	<20
C_3	-	-	-	<460	260	<180	<140	<140	-	<170	<910	<180	<30
C_4	-	-	-	<615	<240	<230	<180	<180	-	<225	<1210	3640	<35
C_5	-	-	-	<730	<300	<280	<220	<220	-	<280	<1500	<300	<45
C_6	-	-	-	<900	<360	<340	<270	<270	-	<330	<1800	<360	<55
Total Gaseous Organics ($\mu g/m^3$)	-	-	-	35,230- 37,935	260- 1355	2000- 3150	500- 1410	4130- 4940	-	26,860- 27,865	2060- 7010	4990- 5830	0- 195
Volatile Organics, TCO ($\mu g/m^3$)													
C_7	6	4	LB	LB	18	5	2	ND	11	44	9	330	54
C_8	27	7	269	250	28	497	23	3100	129	19	27	60	360
C_9	LB	LB	6	5	1	LB	LB	LB	73	ND	LB	130	27
C_{10}	2	5	1	40	27	15	4	28	75	59	18	27	127
C_{11}	54	52	LB	7	13	LB	1	24	98	41	LB	40	73
C_{12}	16	16	14	130	16	LB	LB	LB	82	55	LB	1255	148
C_{13}	2	1	3	13	4	1	2	LB	29	10	2	15	27
C_{14}	2	ND	0.3	9	2	LB	LB	LB	16	64	LB	25	16
C_{15}	LB	ND	2	1	1	3	0.3	LB	7	34	LB	33	30
C_{16}	3	2	1	5	ND	2	ND	LB	6	7	2	5	3
Total Volatile Organics ($\mu g/m^3$)	112	86	295	460	110	523	32	3152	526	333	59	1920	865
Nonvolatile Organics, GRAV, $>C_{16}$ ($\mu g/m^3$)	228	472	117	2,570	310	129	2.0	15,220	1577	910	530	3140	2060
Total Organics (mg/m^3)	>0.34	>0.56	>0.41	38.3- 41.0	0.68- 1.8	2.65- 3.8	0.53- 1.44	22.5- 23.3	>2.1	28.1- 29.1	2.6- 7.6	10.1- 10.9	2.9- 3.1

- =Not measured.

ND = Not detected.

LB = Lower than blank value.

TABLE 31. TOTAL ORGANIC EMISSIONS FROM THE SOLID FUEL-FIRED COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES TESTED

Organics	Bituminous, pulv. dry bottom boilers		Bituminous stokers			Anthracite stokers			Wood stokers
	Site 321	Site 343	Site 220	Site 325	Site 342	Site 320	Site 344	Site 345	Site 219
Gaseous Organics, Field ($\mu g/m^3$)									
C_1	2430	770	-	1100	210	<70	2240	790	-
C_2	<130	<120	-	<130	<120	<130	<130	<150	-
C_3	<185	<180	-	<190	<180	<190	<180	<220	-
C_4	<240	<240	-	<250	<240	<250	<240	<290	-
C_5	<300	8,970	-	<310	<300	<310	<310	<360	-
C_6	<365	<355	-	<370	<370	<370	<370	<420	-
Total Gaseous Organics ($\mu g/m^3$)	2430-3650	9,740-10,635	-	1100-2350	210-1420	0-1320	2240-3470	790-2230	-
Volatile Organics, TCO ($\mu g/m^3$)									
C_7	ND	ND	6	1	1	ND	1	ND	3
C_8	667	43	73	1896	294	10	91	79	43
C_9	80	92	27	477	8	126	75	19	11,922
C_{10}	LB	30	76	13	51	LB	40	LB	1,927
C_{11}	LB	36	126	ND	9	LB	38	6	1,576
C_{12}	LB	30	134	ND	8	LB	112	7	23,690
C_{13}	14	4	26	ND	LB	11	30	LB	1,797
C_{14}	6	3	73	ND	ND	LB	11	4	3,580
C_{15}	2	ND	40	1	222	1	3	1	15,223
C_{16}	LB	5	29	ND	ND	LB	3	ND	872
Total Volatile Organics ($\mu g/m^3$)	769	243	610	2388	593	148	404	116	60,633
Nonvolatile Organics, GRAV, $>C_{16}$ ($\mu g/m^3$)	1150	4410	7546	2730	2710	6110	2120	1430	80,966
Total Organics (mg/m^3)	4.3-5.6	14.4-15.3	>8.2	6.2-7.5	3.5-4.7	6.3-7.6	4.8-6.0	2.3-3.8	>141

- = Not measured.

ND = Not detected.

LB = Lower than blank value.

TABLE 32. TOTAL ORGANIC EMISSIONS FROM THE COMMERCIAL/INSTITUTIONAL RECIPROCATING ENGINES TESTED

Organics	Oil-fired				Gas-fired	
	Site 329	Site 347	Site 348	Site 350	Site 349	Site 353[a]
Gaseous Organics, Field (μg/m^3)						
C_1	1,760	15,230	1,990	3,770	9,607	280,650
C_2	2,540	<210	3,730	5,110	11,785	27,870
C_3	<180	<310	<175	1,780	<920	13,030
C_4	<240	<400	<230	1,650	<1,210	<240
C_5	<280	<500	<290	951,153	<1,500	<360
C_6	<350	<600	<345	-	<1,780	<430
Total Gaseous Organics (μg/m^3)	4,300- 5,350	15,230- 17,250	5,720- 6,760	963,464	21,392- 26,802	321,550- 322,580
Volatile Organics, TCO (μg/m^3)						
C_7	6	ND	ND	ND	44	46
C_8	318	59	35	82	31	186
C_9	1,840	62	48	565	10	680
C_{10}	5,493	317	675	1,784	73	1,901
C_{11}	9,941	430	397	6,446	5	2,134
C_{12}	10,090	811	791	2,865	77	4,499
C_{13}	12,813	1,208	993	3,377	67	4,634
C_{14}	13,917	1,541	397	4,459	39	5,175
C_{15}	10,751	1,189	139	3,673	49	4,600
C_{16}	11,700	856	388	2,768	57	3,620
Total Volatile Organics (μg/m^3)	76,870	6,473	3,863	26,019	452	27,475
Nonvolatile Organics, GRAV, >C_{16} (μg/m^3)	135,000	57,600	51,530	170,000	2,020	34,210
Total Organics (mg/m^3)	216.2- 217.2	79.3- 81.3	61.1- 62.2	>1,160	23.9- 29.3	383.2- 384.3

[a] Dual-fired engine.

- = Not measured.

ND = Not detected.

The ranges shown in the tables result from the treatment of "less than" values. The minimum values of the range were determined by assigning a value of zero to all "less than" values; maximum values assume that the "less than" values are actual concentrations.

Gaseous hydrocarbons are determined in the field, whereas all other organic analyses are performed in the laboratory. The C_1-C_6 field determinations are included here to present an overview of total hydrocarbon emissions.

Large variations exist in total hydrocarbon emissions both among and within all of the source categories tested. This variability is most apparent for the gaseous and nonvolatile organics. Although the data presented in the tables have not been normalized to heat input, the variation is greater than that which could be attributed to differences in excess air or combustion system air leakage. Other factors contributing to the variability, such as system age, fuel, and operating conditions, will be discussed in Section 4.3.

Organic Component Analyses - Further quantitative and qualitative characterizations of organic emissions were conducted in accordance with program procedures as described in Section 4.2. The following subsections will discuss the results of these tests.

Liquid chromatographic separation results - As outlined in Section 4.2.3, the composite samples from the gas- and oil-fired sources and the individual SASS samples from the solid fuel-fired sources are subjected to fractionation into seven components if the nongaseous organic emissions are found to be greater than 0.5 mg/m^3. Gravimetry and IR spectroscopy are used to analyze each fraction for the amount of > C_{16} hydrocarbons and for compound classes, respectively. If the volatile organic content of a sample exceeds 10 percent of the total organics, then a solvent exchange is performed before the separation to preserve volatile organics, and volatile organics (TCO) are measured in each fraction. The results of the LC fractionations are presented in Tables 33, 34, and 35 (an explanation of the sample identification codes is given in Figure 5). The results (TCO, GRAV, and total organics) are presented as emission concentrations. It should be noted that the concentrations shown in Tables 33 through 35 are generally lower than those previously presented in Tables 30 through 32. This discrepancy is attributable to the fact that

TABLE 33. SUMMARY OF LC FRACTIONATIONS FOR GAS- AND OIL-FIRED COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES, mg/m^3

Source category	Site No.	Sample code[a]	Analysis	LC-1	LC-2	LC-3	LC-4	LC-5	LC-6	LC-7	Total
Gas-fired	121	XM	TCO	0.03	0.0004	ND	ND	0.001	0.12	0.0004	0.03
			GRAV	0.003	0.003	0.0004	0.0008	0.01	ND	0.054	0.20
			TOTAL	0.033	<0.01	<0.01	<0.01	0.011	0.12	0.054	0.23
	122	XM	TCO	0.025	0.003	0.003	0.004	0.003	0.002	0.002	0.04
			GRAV	0.005	0.004	0.001	0.008	0.009	0.11	0.08	0.22
			TOTAL	0.03	<0.01	<0.01	0.01	0.01	0.11	0.08	0.26
	333	XRPFMRPR	TCO	0.039	0.035	0.1	0.086	0.35	ND	0.0008	0.6
			GRAV	0.035	LB	0.12	0.3	0.2	0.5	0.36	1.5
			TOTAL	0.074	0.035	0.22	0.39	0.55	0.5	0.36	2.1
Distillate Oil-fired	139	XM	TCO	0.0415	ND	ND	0.113	0.072	0.009	ND	0.24
			GRAV	0.0053	ND	0.0205	0.034	0.022	0.121	0.088	0.29
			TOTAL	0.0468	-	0.0205	0.146	0.094	0.130	0.088	0.53
	140	XM	TCO	0.18	ND	ND	0.0024	ND	0.002	ND	0.19
			GRAV	0.03	0.002	0.009	0.0133	0.01	0.45	0.103	0.38
			TOTAL	0.21	0.002	0.009	0.0157	0.01	0.217	0.103	0.57
	339	XRPFMRPR	TCO	0.07	0.11	0.19	ND	1.00	0.61	0.04	1.99
			GRAV	LB	0.02	0.08	0.94	1.83	2.33	0.98	6.21
			TOTAL	0.07	0.13	0.27	0.94	2.83	2.94	1.02	8.20
Residual Oil-fired	120	XM	TCO	0.11	0.02	0.002	0.03	0.03	0.03	0.19	0.23
			GRAV	0.04	0.13	0.02	0.11	0.09	0.92	ND	1.49
			TOTAL	0.15	0.15	0.02	0.14	0.12	0.95	0.19	1.72
	124	XM	TCO	LB	0.009	0.004	0.003	0.004	0.002	0.003	0.02
			GRAV	LB	LB	LB	LB	LB	0.002	LB	<0.01
			TOTAL	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02
	138	XM	TCO	0.063	0.035	0.012	0.006	0.005	0.027	ND	0.15
			GRAV	0.011	0.012	0.007	0.013	0.022	0.275	0.351	0.69
			TOTAL	0.074	0.047	0.019	0.019	0.027	0.302	0.351	0.84
	337	XRPFMRPR	TCO	0.013	0.0002	0.028	0.12	0.16	0.28	0.95	1.56
			GRAV	0.16	LB	0.031	0.21	0.11	1.03	1.80	3.34
			TOTAL	0.17	<0.01	0.06	0.33	0.27	1.31	2.75	4.90
	346	XRPFMRPR	TCO	0.05	LB	0.003	ND	0.004	0.08	0.19	0.32
			GRAV	0.06	LB	LB	0.14	0.42	0.09	1.03	1.73
			TOTAL	0.11	-	<0.01	0.14	0.42	0.17	1.22	2.05

[a] See Figure 5, page 78 for sample identification and coding.

ND = Not detected.

LB = Lower than blank value.

TABLE 34. SUMMARY OF LC FRACTIONATIONS FOR SOLID FUEL-FIRED COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES, mg/m^3

Source category	Site No.	Sample code[a]	Analysis	LC-1	LC-2	LC-3	LC-4	LC-5	LC-6	LC-7	Total
Bituminous, pulverized dry bottom boilers	321	XM	TCO	ND	ND	ND	ND	ND	ND	ND	ND
			GRAV	LB	0.02	0.006	0.02	0.04	0.26	0.14	0.48
			TOTAL	-	0.02	0.006	0.02	0.04	0.26	0.14	0.48
	343	XM	TCO	0.005	0.015	0.006	0.0009	ND	ND	0.037	0.06
			GRAV	0.18	b	0.17	0.16	0.15	0.06	0.64	1.35
			TOTAL	0.19	0.015	0.18	0.16	0.15	0.06	0.68	1.41
Bituminous, underfeed stokers	220	XM[c]	GRAV	0.43	0.12	0.25	0.26	0.44	3.23	1.0	5.7
Bituminous, spreader stokers	325	XM	TCO	0.93	0.53	0.17	0.02	ND	3.1	ND	4.8
			GRAV	0.22	LB	0.04	LB	LB	0.52	0.40	1.2
			TOTAL	1.15	0.53	0.21	0.02	-	3.62	0.40	6.0
Bituminous, overfeed stokers	342	XM	TCO	0.002	ND	0.002	ND	ND	ND	0.22	0.22
			GRAV	0.016	LB	0.044	0.004	0.085	LB	1.55	1.70
			TOTAL	0.018	-	0.046	0.004	0.085	-	1.77	1.92
Anthracite stokers	320	XM	TCO	ND	ND	ND	ND	ND	ND	ND	ND
			GRAV	0.85	0.02	0.02	0.09	LB	0.55	0.55	2.1
			TOTAL	0.85	0.02	0.02	0.09	-	0.55	0.55	2.1
	344	XM	TCO	0.001	ND	0.02	0.001	0.005	0.0001	0.06	0.08
			GRAV	0.044	LB	LB	0.02	0.12	0.06	1.14	1.38
			TOTAL	0.045	-	0.02	0.021	0.125	0.06	1.20	1.46
	345	XM	TCO	0.05	<0.001	0.004	0.04	<0.001	0.05	0.16	0.30
			GRAV	0.06	LB	LB	ND	0.03	0.04	0.73	0.86
			TOTAL	0.11	<0.001	0.004	0.04	0.03	0.09	0.89	1.16
Wood stokers	219	XM	TCO	89.549	0.587	0.772	0.412	0.561	0.605	0.045	92.531
			GRAV	33.514	10.628	6.273	2.217	2.729	8.163	1.390	64.914
			TOTAL	123.063	11.215	7.045	2.629	3.290	8.768	1.435	157.445

[a] See Figure 5, page 78 for sample identification and coding.

[b] Sample lost in analysis.

[c] Did not meet criterion for TCO analysis.

ND = Not detected.

LB = Lower than blank value.

TABLE 35. SUMMARY OF LC FRACTIONATIONS FOR COMMERCIAL/INSTITUTIONAL RECIPROCATING ENGINES, mg/m^3

Source category	Site No.	Sample code[a]	Analysis	LC-1	LC-2	LC-3	LC-4	LC-5	LC-6	LC-7	Total
Gas-fired	349	XRPFMRPR	TCO	0.045	0.009	0.004	0.002	0.0007	ND	LB	0.06
			GRAV	0.77	LB	0.11	0.09	LB	0.04	0.52	1.54
			TOTAL	0.82	<0.01	0.11	0.09	<0.01	0.04	0.52	1.60
	353[b]	XRPFMRPR	TCO	26.80	1.20	2.86	0.45	0.55	0.14	0.11	32.10
			GRAV	9.50	0.28	1.60	2.34	1.59	2.13	11.50	28.94
			TOTAL	36.30	1.48	4.46	2.79	2.14	2.27	11.61	61.0
Diesel-fired	329	XRPFMRPR	TCO	45.2	4.38	8.69	0.20	0.04	0.008	LB	58.5
			GRAV	110.3	3.40	12.14	3.90	3.15	14.8	3.36	151.0
			TOTAL	155.5	7.78	20.8	4.10	3.19	14.8	3.36	209.5
	347	XRPFMRPR	TCO	3.46	0.79	0.85	0.02	0.02	0.004	ND	5.14
			GRAV	46.96	1.43	2.59	1.31	1.13	4.60	2.49	60.5
			TOTAL	50.4	2.22	3.44	1.33	1.15	4.60	2.49	65.6
	348	XRPFMRPR	TCO	4.14	0.96	2.75	0.02	0.11	0.17	ND	8.0
			GRAV	31.25	1.56	4.89	2.17	1.91	3.85	5.48	51.1
			TOTAL	35.4	2.52	7.64	2.19	2.02	4.02	5.48	59.1
	350	XRPFMRPR	TCO	2.28	0.32	1.21	0.09	ND	0.008	ND	3.91
			GRAV	80.3	3.35	1.49	8.31	5.35	10.0	11.9	134.2
			TOTAL	82.6	3.67	2.70	8.40	5.35	10.0	11.9	138.1

[a] See Figure 5, page 78 for sample identification and coding.

[b] Dual-fired engine - 5 percent oil.

ND = Not detected.

LB = Lower than blank value.

total recovery from the column is not achieved. In addition, in the case of the solid fuel-fired sources, only data from the XAD-2 resin module are shown. The XAD-2 resin module is designed to trap the bulk of the organic emissions, but varying amounts of organics are found in other SASS train component samples.

Careful examination of the data indicates that the amount of organic material recovered in the individual fractions exhibits a pattern that is discernible when source categories are grouped as shown in Figures 6 through 9. The source categories found in each major group are somewhat suprising. Group 1 consists of the two internal combustion source categories plus the wood stoker; Group 2 contains the gas, distillate oil, and bituminous stoker source categories; and the residual oil, anthracite stoker, and bituminous pulverized dry bottom boiler source categories are found in Group 3. It should be noted that the results for each source category are based on limited data from combustion units of varying design, capacity, and age operated at different combustion load and excess air levels. The results, therefore, may not be representative of the overall source category.

The high levels of aliphatic and aromatic compounds found in the LC-1 fraction from the internal combustion sources can be partially explained by incomplete combustion. Oil droplets, in addition to particulates, were collected by the SASS train filters during the testing of the oil-fired and the dual-fired sources. The reason for the high level of organic emissions in the LC-1 fraction from the wood-fired stoker is not as obvious. However, the unit was operated at very low load levels, approximately 40 percent of capacity, during the test period. It is likely that volatile compounds, present to a far greater extent in wood than in coal, were driven off and remained uncombusted because of poor combustion efficiency at this low load level. As will be noted later, this source was also a prolific emitter of POM, indicating poor combustion efficiency during the test period.

For Groups 2 and 3 the largest quantities of extractable organics are found in LC fractions 6 and 7, respectively. The grouping of bituminous stokers with the gas and distillate units that together comprise Group 2 is surprising, as is the inclusion of residual oil units with the bituminous and anthracite sources that make up Group 3. The data would appear to be more credible if the bituminous stokers were found in Group 3 and the residual oil units in Group 2.

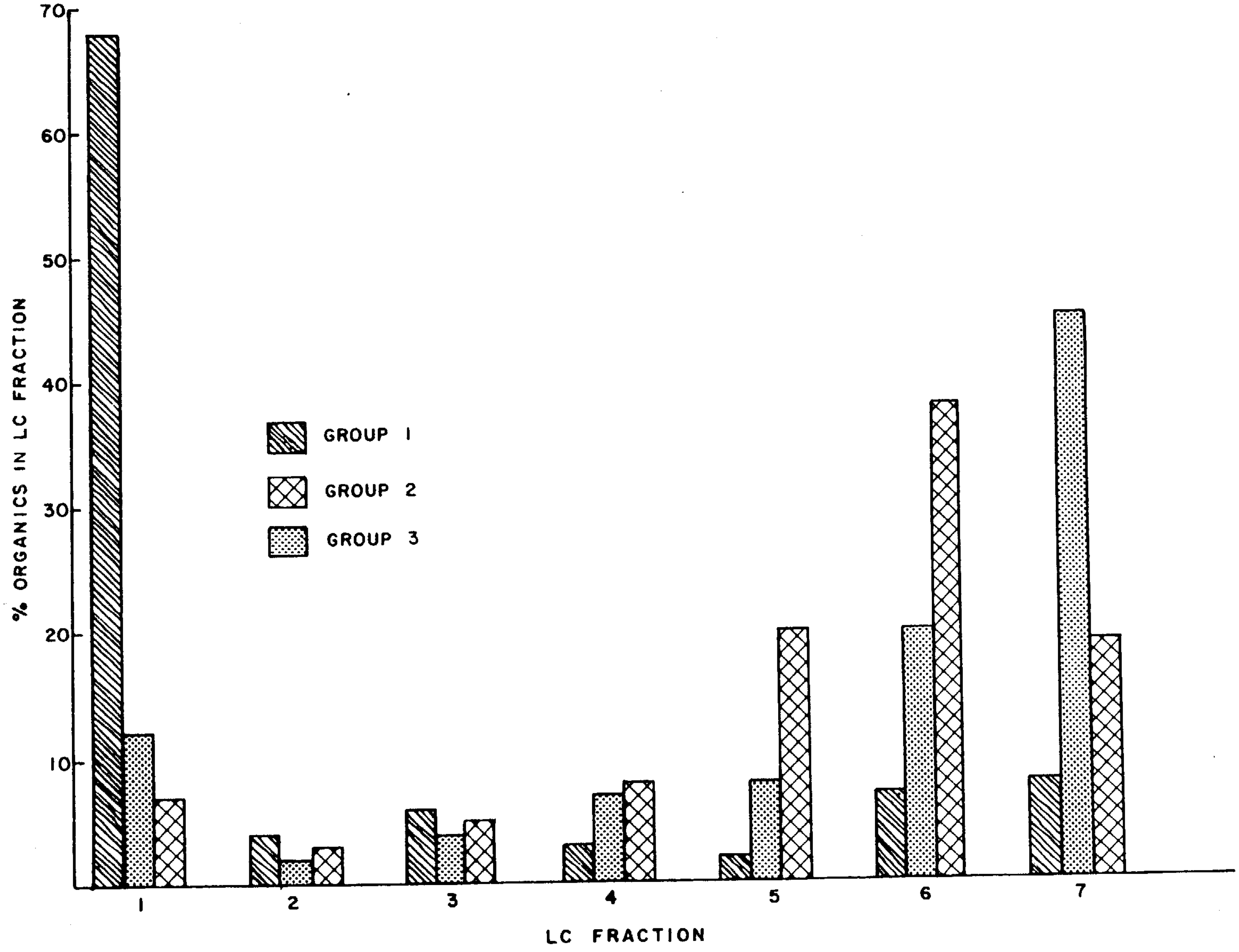


Figure 6. Average distribution of organics in LC fractions by major groups (see Figures 7, 8 and 9 for identification of source categories within groups).

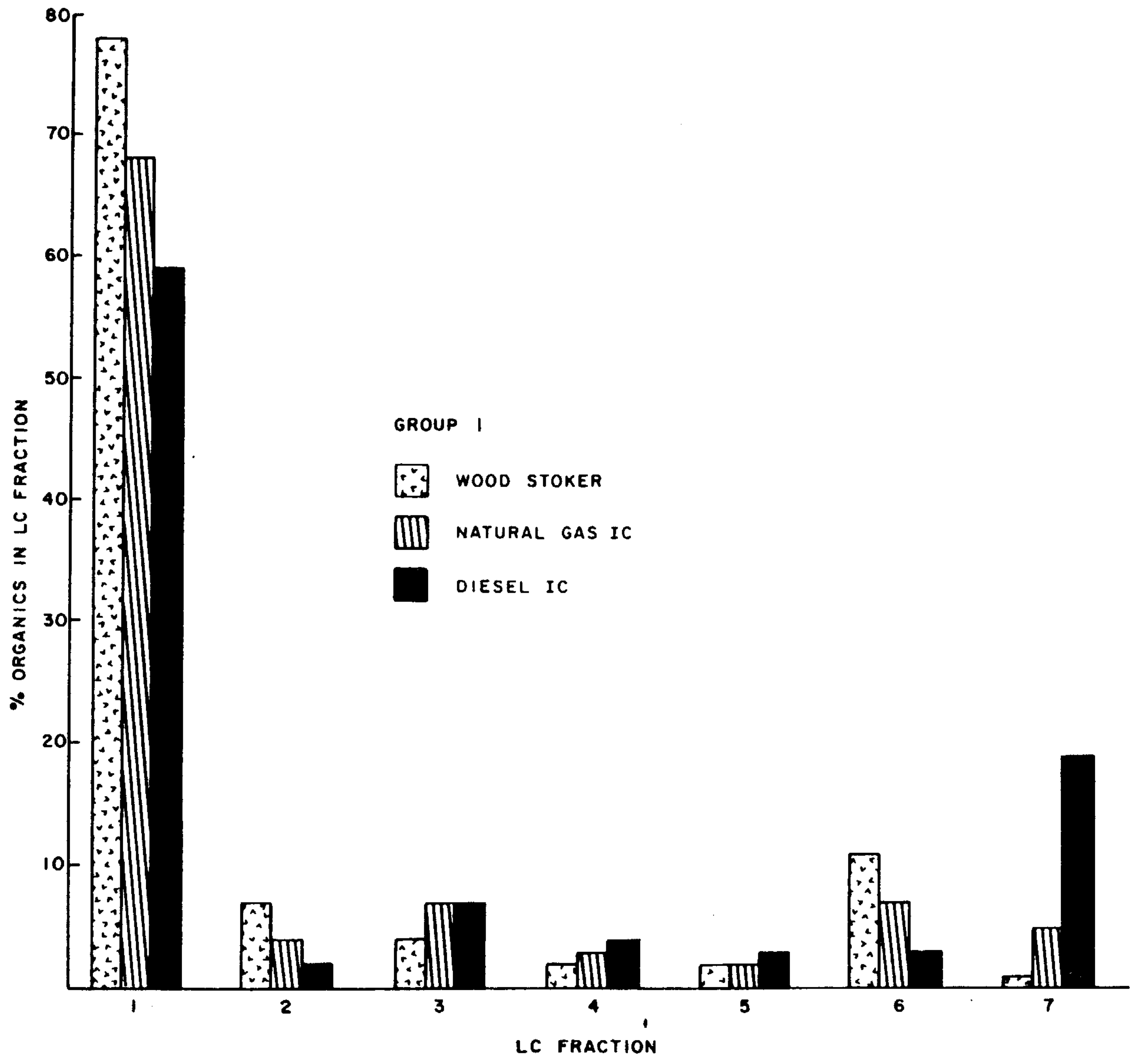


Figure 7. Percent of extractable organics found in each LC fraction - Group 1.

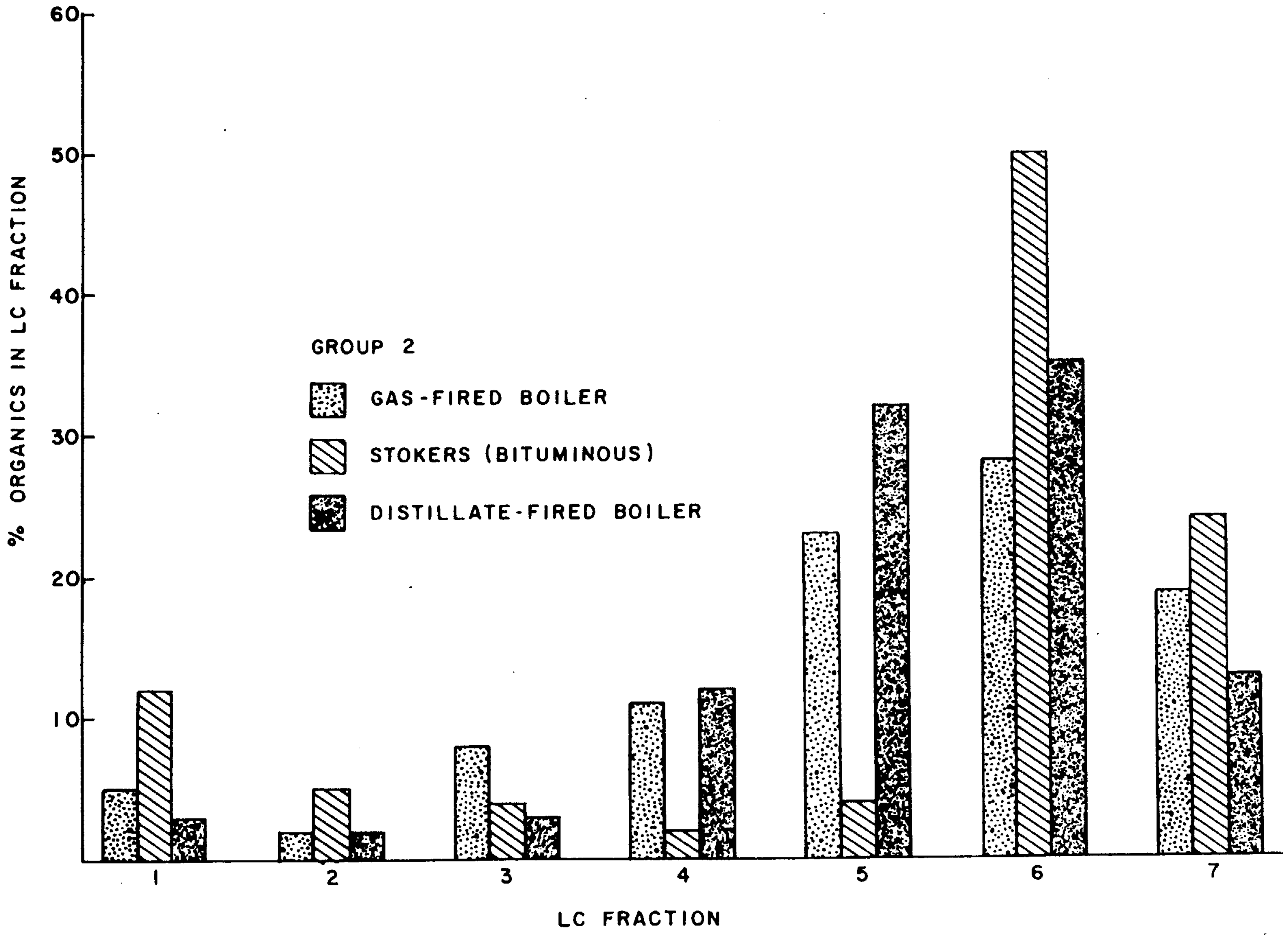


Figure 8. Percent of extractable organics found in each LC fraction - Group 2.

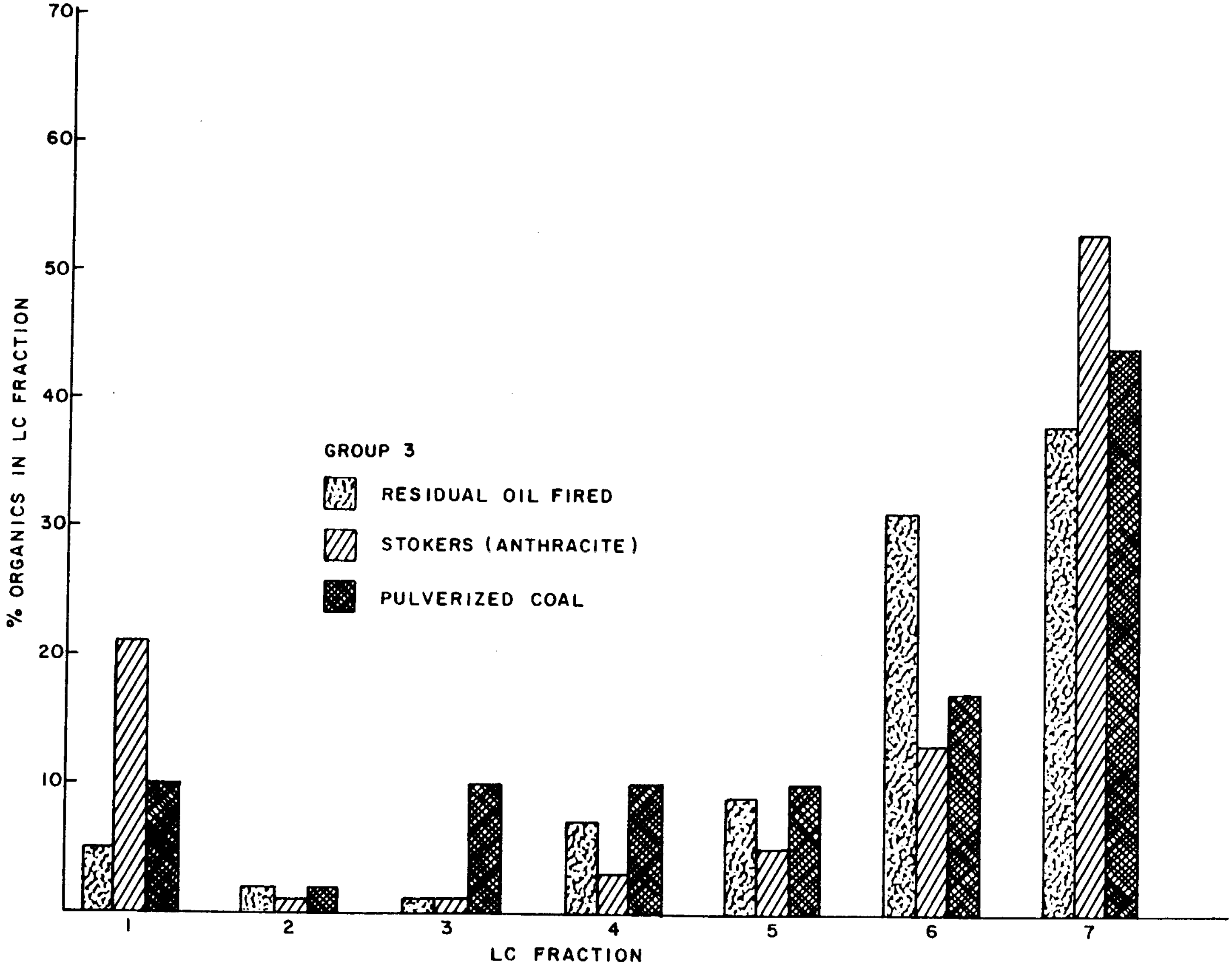


Figure 9. Percent of extractable organics found in each LC fraction - Group 3.

Additional data are needed to determine whether the LC fraction distribution patterns shown in this study of commercial/institutional sources are truly representative of the organic emissions of these source categories.

Infrared analysis results - Infrared (IR) spectrophotometry is used to determine organic compound classes by functional group in neat sample concentrates and LC fraction residues. Table 36 presents results of the IR analyses of XAD-2 resin samples and LC fractions from the commercial boilers and engines tested. Aliphatic hydrocarbons, aromatics, esters, ketones, and carboxylic acids are the compound classes typically found. Benzoates and phthalates are common contaminants, and their presence in the spectra of the samples should be discounted.

Low resolution mass spectroscopy results - As described in Section 4.2.3, low resolution mass spectrometric (LRMS) analysis for compounds and compound classes is performed on any LC fraction of a flue gas sample, the source concentration of which exceeds 0.5 mg/m^3. Table 37 presents results of LRMS analyses of LC fractions meeting this criterion.

Results of GC/MS analysis for Polycyclic Organic Matter (POM) - All organic sample concentrates were analyzed by GC/MS for POM. Table 38 presents the results of POM analyses for the commercial/institutional sources. The compounds shown in brackets represent isomers or compounds of identical molecular weight that could not be definitively identified by GC/MS techniques used in this program. Additional sampling and Level II GC/MS analysis would be required to identify compounds emitted from those sources.

TABLE 36. COMPOUND CLASSES IDENTIFIED BY INFRARED ANALYSIS

Site - Sample	Original sample	LC-1	LC-2	LC-3	LC-4	LC-5	LC-6	LC-7
Gas-fired boilers								
121-XM	Benzoates, other Est, Gly, CA	a	a	a	a	Pth	Aro, CA, CS, Est, Gly; poss: Ald, Pnl	Aol, CA, CS; poss: N
122-XM	Est, Gly, Kt/Ald	a	a	a	a	Est	Ali Est, Aol	Ali Est; poss: Pth/benzoates
123-XM	CA, Est, Gly	b	b	b	b	b	b	b
333-XRPFMRPR	Ali, Aro, CA; poss: Aol, Est, Kt	a	a	Aro, Est(tr); poss: HNC	Aro Est & Kt, sat & unsat Est & Kt	Aro Est & Kt, sat & unsat Est & Kt	Aro, CA, Est, Kt	Aro, CA, Est;
352-XRPFMRPR	A, Est; poss: Aol, Kt	b	b	b	b	b	b	b
Distillate oil-fired boilers								
139-XM	Am, Aol, Est	a	a	a	Est; poss: Am	a	Est, Aol/Gly	CS; poss: A, Kt, Am/N
339-XRPFMRPR	Est, Kt; poss: Am, Aol, CA	a	a	a	Ali & Aro Est; poss: Pth	Aro Est	Aro CA, Est	CA, Est
Residual oil-fired boilers								
120-XM	CA, Est, Gly, Kt/Ald; poss: Cl, N	Ali Hyd	Si(tr)	c	Est, Gly/Aol, N; poss: Aro, TC	Am, Aol, Est, N	CA, Est, Kt, Gly/Aol, SC; poss: Cl, N	c
124-XM	Est, Gly/Eth; poss: CA	a	a	a	a	a	a	c
138-XM	Aol, Ald/Kt, Est	a	a	a	a	a	Aol, CA, Est, Gly, Ald/Kt; poss: CS, Eth/Pnl	CA, CS, Aol/Gly; poss: N
337-XRPFMRPR	Ali, Aro, CA;	Ali	a	a	Aro Est & Kt, unsat Est & Kt; poss: HNC	Est, Aro Kt, unsat Ali & Kt, sat Ali; poss: HNC	Aro & unsat CA	Aro, Aro & unsat CA
346-XRPFMRPR	Ali, Aro, Est;	a	a	a	Ali & Aro Est; poss: Am, HNC	Aro & unsat Est; poss: Kt	a	Aro, CA, Est

(continued)

TABLE 36 (continued)

Site - Sample	Original sample	LC-1	LC-2	LC-3	LC-4	LC-5	LC-6	LC-7
Bituminous, pulverized dry bottom boilers								
321-XM	Ali, Aro, Eth, Kt	a	a	a	a	a	Aro Eth	a
343-XM	Ali, Aro, Est, Kt	Ali Hyd, Aro Est	a	Aro, Eth, Aro Est	Aro, Ali & Aro Est; poss: Eth, HNC	Ali, Aro, Aro Est; poss: HNC	Ali, Aro, Aro Est	CA, Ali, Aro, Est
Bituminous stokers								
220-XM	Fused Aro, Ali, Kt	Fused Aro, Est	Fused Aro, Est, Si	Fused Aro, Pth Est	Pth Est	Est, Eth	Est, Eth	Est, Eth
325-XM	Ali & Aro Hyd, Est; poss: Ali, Aro, Kt	Ali & Aro Hyd	a	Aro Hyd	Est	a	Aro, CA	Aro Eth; poss: Aro
342-XM	Ali, Aro, CA, Est; poss: Am, HNC, Kt, Pnl	a	a	a	a	a	a	Ali, Aro, CA, Est
Anthracite stokers								
320-XM	Ali, Aro, CA; poss: Am, Aol, Kt	Ali Hyd	a	c	c	Ali, Aro, Est; poss: Am, Aol, Kt	Ali, Aro, CA	c
344-XM	A, Ali, Aro, Est	a	a	a	a	Est	Est	CA, Ali, Aro, Est, Pnl
345-XM	A, Ali, Aro, Est; poss: Am, Aol, Kt	a	a	a	a	a	a	A, Ali, Aro, Aol, Est, Kt
Wood stokers								
219-XM	Fused Aro	Fused Aro	Fused Aro, Est	Fused Aro, Est(tr), Kt(tr)	Fused Aro, Kt	Fused Aro, Est	Fused Aro, Est	Fused Aro, Est, Eth

(continued)

TABLE 36 (continued)

Site - Sample	Original sample	LC-1	LC-2	LC-3	LC-4	LC-5	LC-6	LC-7
Oil-fired reciprocating engines								
329-XRPFMRPR	Ali, Aro; poss: Ald, Am, Est, Kt	Ali Hyd	Ali Hyd	Ali Hyd	Ali	Ali, unsat Est	Ali, unsat Est	-
347-XRPFMRPR	Ali, Aro; poss: Am, CA	Ali	Ali, Aro	Ali, Aro	Ali, Aro	[c]	Ali, CA;	[c]
348-XRPFMRPR	Est, Ali, Aro	Ali	[d]	Aro	Ali, Aro, Est(tr)	Ali, Aro, Est(tr),	Ali, Aro	Ali, Aro, CA
350-XRPFMRPR	Ali, Aro; poss: Am, Ald, Est, Kt	Ali Hyd,	Aro	Ali, Aro	Ali, Aro Est, Kt	Ali, Aro	Ali, Aro; poss: Est, HNC	Ali, Aro, Est
Gas-fired reciprocating engines								
349-XRPFMRPR	Aro, sat & unsat Ali; poss: Est	Ali, unsat Aro	[a]	Aro, Eth; poss: Si	[a]	[a]	[a]	CA, Est
353-XRPFMRPR[e]	Ali, Aro; poss: A, Ald, Am, Kt, N	sat & unsat Ali Hyd	[a]	Ali, Aro	Ali, Aro	Ali, Aro	Ali, Aro, Pnl	Ali, Aro, A, CA

[a] Did not meet criterion for IR analysis.

[b] Did not meet criterion for LC separation.

[c] Content of spectra less than blank.

[d] Sample lost.

[e] Dual-fired engine.

Abbreviations used for IR data

A	acids
Ald	aldehydes
Ali	aliphatic(s)
Am	amides
Aol	alcohols
Aro	aromatic(s)
CA	carboxylic acids
Cl	chlorinated hydrocarbons
CS	carboxylic acid salts
Est	esters
Eth	ethers
Gly	glycols
HNC	heterocyclic nitrogen compounds
Hyd	hydrocarbons
Kt	ketones
N	nitro compounds
Pnl	phenols
Pth	phthalates
sat	saturated
Si	silicones
SC	sulfur compounds
TC	thiocarbonyl compounds
unsat	unsaturated
(tr)	trace
poss:	possible compounds

TABLE 37. ORGANIC EMISSIONS IDENTIFIED BY LRMS ANALYSIS IN LC FRACTIONS

Site - Sample	LC-1	LC-2	LC-3	LC-4	LC-5	LC-6	LC-7
Gas-fired boilers							
121-XM	-	-	-	-	Est	Est, Aol, A, CS	Aol, CA, CS, N
122-XM	-	-	-	-	Est	Est, Aol	Est
123-XM	-	-	-	-	-	-	-
333-XRPFMRPR	-	-	-	-	-	Benzoic acid, CA	-
352-XFPFMRPR	-	-	-	-	-	-	-
Distillate oil-fired boilers							
139-XM	-	-	-	Est, poss: Am	-	Est, Aol/Gly	CA; poss: CA, N, Am
140-XM	Ali	-	-	-	-	Est, Aol/Gly, CA	Est, Aol/Gly/CA
339-XRPFMRPR	-	-	-	-	Pnl	CA	CA
Residual oil-fired boilers							
120-XM	Ali	Si	-	SC, Est, Eth, Aol, Ali/Kt	Est, Aol	Pth, FA, Aol, CA Ald/Kt	-
124-XM	-	-	-	-	-	-	-
138-XM	-	-	-	-	-	Est, Aol/Gly, CA Ald/Kt	Aol/Gly, CA, CS
337-XRPFMRPR	-	-	-	-	-	Pnl, Benzoic acid	-
346-XRPFMRPR	-	-	-	-	-	-	Benzoic acid, benzoate esters, Pnl
Bituminous, Pulverized dry bottom boilers							
321-XM	-	-	-	-	-	-	-
343-XM	-	-	-	-	-	-	Benzoic acid, Pnl
Bituminous stokers							
220-XM	-	-	-	-	-	Ali A, Pth	Aro A, Ali A, Pth
325-XM	-	-	-	-	-	CA	-
342-XM	-	-	-	-	-	-	CA

(continued)

TABLE 37 (continued)

Site - Sample	LC-1	LC-2	LC-3	LC-4	LC-5	LC-6	LC-7
Anthracite stokers							
320-XM	Ali	-	-	-	-	Pnl, A	Pnl, CA, Pth
344-XM	-	-	-	-	-	-	Benzoic acid, CA, Pnl
345-XM	-	-	-	-	-	-	Benzoic acid, CA Pnl, Si
Wood stokers[a]							
219-XM	phenanthrene methyl phenanthrene pyrene methyl pyrene ethyl pyrene chrysene benzopyrene	pyrene methyl pyrene ethyl pyrene phenanthrene methyl phenanthrene chrysene methyl chrysene benzopyrene methyl benzopyrene 3-methylcholanthrene dibenzoanthracene methyl dibenzoanthracene indeno(1,2,3-cd)pyrene	acenaphthylene phenanthrene methyl phenanthrene pyrene chrysene methyl chrysene benzopyrene methyl benzopyrene coronene dibenzopyrene 3-methylcholanthrene indeno(1,2,3-cd)pyrene	ketones fluorenone anthraquinone benzanthrone pyrene acenaphthylene	ketones fluorenone benzanthrone	phenols, ketones N-heterocyclic fluorenone quinoline methyl quinoline ethyl quinoline acenaphthylene	aliphatic acids acids, esters silicones phthalates dioctyl phthalates
Oil-fired reciprocating engines							
329-XRPFMRPR	Ali, Aro	Aro, Ali	subs. naphthalenes	subs. naphthalene, pyrene	Aol, Pnl, Est	CA, Aol	CA, Aol
347-XRPFMRPR	Ali	Ali, Aro, Est	subs. naphthalenes	Est, subs. naphthalenes	Pnl, Est	Benzoic acid, CA, Est	CA, A
348-XRPFMRPR	Ali	-	subs. naphthalenes, phenanthrenes	Est, subs. naphthalenes	subs. naphthalenes, Est	Est	Benzoic acid, CA
350-XRPFMRPR	Ali	Aro, Ali	subs. naphthalenes, phenanthrenes, pyrene	Est, subs. naphthalenes, fluorenone	+	+	CA, Benzoic acid

(continued)

TABLE 37 (continued)

Site - Sample	LC-1	LC-2	LC-3	LC-4	LC-5	LC-6	LC-7
Gas-fired reciprocating engines							
349-XRPFMRPR	Ali	-	-	-	-	-	CA, Est
353-XRPFMRPR	Ali	-	subs. naphthalenes, phenantnrenes, pyrene	subs. naphthalenes	subs. naphthalenes, Pnl	Pnl	CA, A

- Did not meet criteria for LRMS analysis.

+ Sample lost in analysis.

[a] GC/MS indicated the presence of the listed compounds or their isomers.

Abbreviations used for LRMS data

A	acids
Ald	aldehydes
Ali	aliphatic(s)
Am	amides
Aol	alcohols
Aro	aromatic(s)
CA	carboxylic acids
Cl	chlorinated hydrocarbons
CS	carboxylic acid salts
Est	esters
Eth	ethers
FA	fatty acids
Gly	glycols
HNC	heterocyclic nitrogen compounds
Hyd	hydrocarbons
Kt	ketones
N	nitro compounds
Pnl	phenols
Pth	phthalates
sat	saturated
Si	silicones
SC	sulfur compounds
subs.	substituted
TC	thiocarbonyl compounds
unsat	unsaturated
(tr)	trace
poss:	possible compounds

TABLE 38. POM EMISSIONS FROM THE COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES TESTED

Source category	Site No.	Sample code	POM compound[a]	Emission concentration (μg/m³)
Gas-fired boilers	121	XM	Naphthalene	0.9
			Trimethyl propenyl naphthalene (2 isomers)	0.4
	122	XM	Naphthalene	0.7
			Trimethyl propenyl naphthalene (2 isomers)	0.2
	123	XM	ND	-
	333	XRPFMRPR	Naphthalene	141.8
			Acenaphthalene	35.2
			Phenanthrene	5.8
			Fluoranthene	3.7
			Pyrene	14.2
	352	XRPFMRPR	ND	-
Distillate oil-fired boilers	139	XM	ND	-
	140	XM	ND	-
	339	XRPFMRPR	Naphthalene	146.1
Residual oil-fired boilers	120	XM	Naphthalene	31.4
			C2 substituted naphthalene	4.4
			Fluorene-9-one or benzo-c-cinnocine	1.9
			Phenanthrene or anthracene	5.0
			Methyl phenanthrene or naphtho-pyran-dione	2.2
			Benzanthracene	2.8
	124	XM	Naphthalene	7.9
	138	XM	Naphthalene	0.35
			Trimethyl propenyl naphthalene	2.24
	337	XRPFMRPR	ND	-
	346	XRPFMRPR	ND	-
Bituminous, pulverized dry bottom boilers	321	XR	Naphthalene	3.35
			Biphenyl	0.76
		XM	Naphthalene	0.56
		FC	Naphthalene	3.26
	343	XM	ND	-
		FC	ND	-
		CC	ND	-
		PR	ND	-
Bituminous underfeed stokers	220	PR	None	< 0.06
	220	FC	Naphthalene	1.3
	220	XM	Naphthalene	346

(continued)

TABLE 38 (continued)

Source category	Site No.	Sample code	POM compound^a	Emission concentration ($\mu g/m^3$)
Bituminous underfeed stokers (continued)	220	XM	Phenanthrene	536
			Methyl phenanthrene	39
			Methyl phenanthrene	31
			Fluoranthene	458
			Pyrene	461
			Benz(a)fluorene or	11
			Methylpyrenes	43
				9
				26
			Chrysene	41
			Benz(a)anthracene	244
			Methyl benz(a)anthracene	22
			Perylene or	178
			Benzo(e)pyrene	22
			Benzo(a)pyrene	129
			Benzo(ghi)perylene or	6
			Indeno(1,2,3-CD)pyrene or	12
			Dibenzo(def,mno)chrysene	70
			Benzo(b)chrysene or	6
			Dibenz(a,h)anthracene	5
				19
				16
			Coronene	2
			Dibenz(a,i)pyrene	29
			Dibenz(a,h)pyrene	6
Bituminous spreader stokers	325	XR	Naphthalene	29.0
Bituminous overfeed stokers	342	XM	ND	-
		PR	ND	-
		CC	ND	-
Anthracite stokers	320	XR	Biphenyl	0.51
			Phenanthrene	0.14
	344	XM	ND	-
		PR	ND	-
		FC	ND	-
		CC	ND	-
	345	XM	Naphthalene	2.9
		PR	ND	-
		FC	ND	-
		CC	ND	-
Wood underfeed stokers	219	XM	Naphthalene	6553
			Biphenyl	1902
			Fluorene	1631
			Phenanthrene	7753
			Methyl phenanthrene	458
			Methyl phenanthrene	820
			Methyl phenanthrene	533

(continued)

TABLE 38 (continued)

Source category	Site No.	Sample code	POM compound[a]	Emission concentration ($\mu g/m^3$)
Wood underfeed stokers (continued)	219	XM	Phenylnaphthalene	1144
			Fluoranthene	3875
			Pyrene	4166
			Methylpyrene or	176
			Benzo(a)fluorene	493
				137
				467
			Benzo(g,h,i)fluoranthene	1822
				308
			Chrysene	689
			Benzo(a)pyrene or	2827
			Benzo(e)pyrene or	
			Benzo(k)fluoranthene or	101
			Benz(e)acephenanthrylene	3099
			Dibenzo(def,mno)chrysene or	1587
			Benzo(g,h,i)perylene or	1764
			Indeno(1,2,3-CD)pyrene	719
			Benzo(b)chrysene or	113
			Dibenz(a,h)anthracene	554
			Dibenz(a,i)pyrene	1188
			Dibenz(a,h)pyrene	434
			Benzo(c)fluoranthene	384
			Methyl benz(a)anthracene	66
			Methyl benz(a)anthracene	298
			Methyl benz(a)anthracene	214
			Binaphthalene	844
			Coronene	571
		PR	Naphthalene	10
			Phenanthrene	61
			Fluoranthene	92
			Pyrene	150
			Benzo(a)fluorene or	7.6
			Methylpyrene	3.4
			Methylpyrene	10.
			Methyl benz(a)anthracene	11.8
			Methyl benz(a)anthracene	8.4
			Benzo(a)pyrene or	21.
			Benzo(e)pyrene or	
			Perylene	202
			Chrysene	230
			Benzo(g,h,i)perylene or	55
			Indeno(1,2,3-CD)pyrene	104
			Coronene	30
			Dibenz(a,h)pyrene	24
		FC	Naphthalene	5.0
		CC	Naphthalene	8.4
			Phenanthrene	5.0
			Pyrene	0.2
			Fluoranthene	0.3

(continued)

TABLE 38 (continued)

Source category	Site No.	Sample code	POM compound[a]	Emission concentration ($\mu g/m^3$)
Gas-fired reciprocating engines	349	XRPFMRPR	ND	-
	353[b]	XRPFMRPR	Naphthalene	352.4
			Biphenyl	54.8
			Methylnaphthalene	258.4
			Methylnaphthalene	195.8
			Dimethylnaphthalene	125.3
			Dimethylnaphthalene	266.3
Oil-fired reciprocating engines	329	XRPFMRPR	Naphthalene	611.2
			Biphenyl	100.1
			Phenanthrene	147.3
			Methylfluorene	45.7
			Methylphenanthrene	73.6
			Methylphenanthrene	41.2
			Fluoranthene	14.7
			Pyrene	17.7
	347	XRPFMRPR	Naphthalene	29.6
			Biphenyl	8.1
			Phenanthrene	24.2
			Methylphenanthrene	16.1
			Methylphenanthrene	8.1
	348	XRPFMRPR	Naphthalene	155.2
			Biphenyl	10.5
			Fluorene	10.5
			Phenanthrene	68.3
			Methylphenanthrene	57.8
			Methylphenanthrene	26.3
	350	XRPFMRPR	Naphthalene	184.0
			Methylnaphthalene	155.3
			Methylnaphthalene	122.6
			Dimethylnaphthalene	112.4
			Dimethylnaphthalene	224.8
			Phenanthrene	51.1
			Methylphenanthrene	20.4

ND = Not Detected.

[a] Compounds shown in brackets and listed as "or" are either isomers or compounds with similar mass to charge values.

[b] Dual-fired engine.

4.3 ANALYSIS OF DATA EVALUATION AND PROGRAM TEST RESULTS

4.3.1 Emissions of Criteria Pollutants

The particulate, NO_x, CO, and total organic emissions data collected in this program are presented in Tables 39, 40 and 41 for gas- and oil-fired sources, solid fuel-fired sources and internal combustion reciprocating engines, respectively. Emissions of SO_2 were not measured in the test program.

4.3.1.1 Gas- and Oil-Fired Boilers

As shown in Table 39, the calculated emission factor data variability is large for particulate and HC emissions from gas- and oil-fired sources. Insufficient data were collected for NO_x and CO to calculate variabilities. As indicated in Section 4.1, the existing data base for these pollutants was deemed adequate. The large variability shown for particulates and HC can be attributed to the limited number of data points for each source category and to differences in operating conditions. The gas-fired boiler at site 333, for example, was operated at low excess air levels (approximately 10 percent) and was found to emit relatively high levels of C_1-C_6 and other hydrocarbons. Gas-fired boilers at sites 121, 122, and 123, which were operated at higher excess air levels, emitted very little particulate and HC, although C_1-C_6 determinations were not made at these sites. In the case of the oil-fired sites, the variability of particulate emissions can be largely attributed to residual oil site 337 and distillate oil site 339. Particulate emission factors for these sites were much higher than the emission factors for the other sites tested. These same sites, particularly site 339, also contributed to the variability of the HC emission factor. However, in all cases, the emission factor values are within a factor of 3 of the mean of the existing data base for particulates and HC. The individual values, therefore, are reasonable and add to an already adequate data base.

4.3.1.2 Solid Fuel-Fired Combustion Sources

Emission factor data are presented in Table 40 for the solid fuel-fired combustion sources tested in this program. The variability of the particulate and total hydrocarbon emission factor data for the three uncontrolled anthracite stokers tested is also shown in the table. Calculation of the

TABLE 39. CRITERIA POLLUTANT EMISSION FACTORS FOR THE GAS- AND OIL-FIRED COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES TESTED

Source category	Site No.	Emission factor (ng/J)			
		Particulates	NO_x	CO	HC
Gas-fired boilers	121	< 0.001	-	-	> 0.1
	122	< 0.001	-	-	> 0.15
	123	< 0.001	-	-	> 0.1
	333	0.17	26	-	10.0
	352	1.9	44	9	2.3
	$\bar{X}$	0.41	35	9	2.5
	$s(\bar{X})$	0.37	-	-	3.0
	$ts(\bar{X})/\bar{X}$	2.5	-	-	3.3
Distillate oil-fired boilers	139	3.7	-	-	1.13
	140	4.0	-	-	0.27
	339	16	-	68	9.3
	$\bar{X}$	7.9	-	68	3.6
	$s(\bar{X})$	4.0	-	-	2.9
	$ts(\bar{X})/\bar{X}$	2.2	-	-	3.4
Residual oil-fired boilers	120	8.9	-	-	0.66
	124	6.2	-	-	10.3
	138	5.6	-	-	0.9
	337	34	-	49	7.0
	346	8.0	-	3.2	6.1
	$\bar{X}$	12.5	-	26.1	5.0
	$s(\bar{X})$	5.4	-	-	1.9
	$ts(\bar{X})/\bar{X}$	1.2	-	-	1.0

- = Not measured

$\bar{X}$ - Mean

$s(\bar{X})$ - Standard error of the mean

$ts(\bar{X})/\bar{X}$ - Variability

TABLE 40. CRITERIA POLLUTANT EMISSION FACTORS FOR THE SOLID FUEL-FIRED COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES TESTED

Source category	Site No.	Emission factor (ng/J)			
		Particulates[a]	NO_x	CO	HC
Bituminous, pulverized dry bottom boilers	321	2560	248	< 60	2.4
	343	1470	280	-	2.0
	$\bar{X}$	2015	264	-	2.2
Bituminous stokers					
Underfeed	220	12	-	-	> 4.4
Spreader	325	1210	259	-	5.8
Overfeed	342	350	189	0.6	9.4
Anthracite stokers	320	535	-	-	6.5
	344	502	-	-	6.3
	345	171	-	-	1.8
	$\bar{X}$	403	-	-	4.9
	$s(\bar{X})$	116	-	-	1.5
	$ts(\bar{X})/\bar{X}$	1.24	-	-	1.35
Wood stokers	219	39	8	< 20	> 80.9

[a] Uncontrolled emission factors; measured particulate emission factors were 15 ng/J for Site 343, 363 ng/J for Site 325, and 105 ng/J for Site 342.

- = Not measured

$\bar{X}$ - Mean

$s(\bar{X})$ - Standard error of the mean

$ts(\bar{X})/\bar{X}$ - Variability

TABLE 41. CRITERIA POLLUTANT EMISSION FACTORS FOR THE COMMERCIAL/INSTITUTIONAL RECIPROCATING ENGINES TESTED

Source category	Site No.	Emission factor (ng/J)			
		Particulates	NO_x	CO	HC
Gas-fired engines	349	0.1	765	450	5.2
	353[a]	10	-	590	242
	$\bar{X}$	5	-	520	124
Oil-fired engines	329	68	950	-	145
	347	25	1243	167	104
	348	14	1056	-	74
	350	59	-	170	754
	$\bar{X}$	41.5	1083	169	269
	$s(\bar{X})$	13	86	-	162
	$ts(\bar{X})/\bar{X}$	1.0	0.34	-	1.9

[a] Dual-fired engine (5 percent oil).

\- = Not measured

$\bar{X}$ - Mean

$s(\bar{X})$ - Standard error of the mean

$ts(\bar{X})/\bar{X}$ - Variability

variability of the emission factor data for the bituminous- and wood-fired sources tested was not possible because of the limited number of units tested within each source category.

The two bituminous, pulverized dry bottom boilers tested exhibited a twofold variation in uncontrolled particulate emissions after correction for a design efficiency of 99 percent for the one unit (site 343) with a control device. The difference in the uncontrolled particulate emission factors could be a function of the combustion source or could indicate that the control system (mechanical separators and wet scrubber) was operating at approximately 99.7 percent during the test period. Similarly, adjustment of the particulate emission factors for the two bituminous stokers (sites 325 and 342) controlled by mechanical separators, using the design efficiencies of 70 percent for each unit, could have some effect on the variability of the particulate emission factors shown for the bituminous stokers. However, the principal cause of particulate emission factor variability for these stokers can be attributed to the differences in stoker firing methods.

The calculated variabilities of the particulate and HC emission factors for the three anthracite stokers tested exceeded 70 percent for both pollutants. The three units were underfeed stokers and, thus, firing method should not be a factor in the calculated variabilities for the two pollutants. The data base for anthracite stokers is still inadequate for particulates because of the data variability and the high ambient severity factors (> 0.05) associated with particulate emissions from these sources. The hydrocarbon emission data base for anthracite stokers is adequate because of the low ambient severity factor associated with hydrocarbon emissions as measured in this program.

Only one underfeed wood-fired stoker was tested in this program. The heat input rate to this unit during testing was well below design and it is not possible to draw firm conclusions regarding particulate and HC emissions from commercial/institutional wood-fired stokers from this one test. As will be discussed later, this wood-burning stoker is most noteworthy for its high POM emissions.

4.3.1.3 Internal Combustion Reciprocating Engines

Four oil-fired, one gas-fired, and one dual-fired reciprocating engines were tested in this program. The results are shown in Table 41. The calculated variabilities exceed 0.7 for the particulate and hydrocarbon emissions from the oil-fired sites. Particulate and HC emissions from the dual-fired site are appreciably higher than corresponding emissions from the gas-fired engine tested and appear to be more representative of emissions from the oil-fired engines. As will be noted later, POM emissions from the dual-fired site are also much more representative of those from the oil-fired engines than POM emissions from the gas-fired site. These observations are of interest because the amount of oil used by the dual engine during the test represents only about 5 percent of the total heat input.

4.3.1.4 Comparison of Criteria Pollutant Emission Factors

In Table 42, the emission factors for the sources tested in this program are compared with emission factors derived from the existing data base and with EPA emission factors.[24] Some of the data used to compile the EPA emission factors are contained in the existing data base. Thus, the combined emission factor data from this study and the existing data base should generally be more reliable than the EPA emission factors. However, for many source categories, and particularly the solid fuel-fired source categories, the combined current study and existing data base contain very few data points, and the combined data base must be considered inadequate for these commercial/institutional sources.

Despite the variability of the data, the mean criteria pollutant emission factors for gas- and oil-fired boilers are in good agreement overall with the existing data base and EPA emission factors. Emission factor data for the coal-fired sources are much more limited: only a few units were tested in this study; the existing data base is generally nonexistent; and the EPA emission factor data for commercial/institutional sources are based on data of questionable adequacy gathered several years ago before the EPA adopted standard test methods for measuring criteria pollutants.

TABLE 42. COMPARISON OF CRITERIA POLLUTANT EMISSION FACTORS FOR COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES

Combustion source type	Data source	Emission factor (ng/J)				
		Particulates	NO_x	SO_2[a]	CO	HC
Gas-fired boilers	Current study	0.41	35	ND	9	2.5
	Existing data	2.4	41	ND	12	5.8
	Combined existing data and current study	1.7	40	ND	12	4.8
	EPA: AP-42	2-6	50	0.26	8	3
Distillate oil-fired boilers	Current study	7.9	ND	ND	68	3.6
	Existing data	5.5	51	93	3.2	2.2
	Combined existing data and current study	6.0	51	93	8	2.5
	EPA: AP-42	6	68	106	15	3
Residual oil-fired boilers	Current study	12.5	ND	ND	26	5.0
	Existing data	49.9	166	438	2.1	1.1
	Combined existing data and current study	37	166	438	3.6	2.2
	EPA: AP-42	37	172	464	15	3
Bituminous, pulverized dry bottom boilers	Current study	2015	264	ND	ND	2.2
	Existing data	ND	ND	ND	ND	ND
	Combined existing data and current study	2015	264	ND	ND	2.2
	EPA: AP-42	3406[b]	352	766	20	6
Bituminous stokers[c]	Current study	520	214	ND	ND	6.6
	Existing data	ND	ND	ND	ND	ND
	Combined existing data and current study	520	214	ND	ND	6.6
	EPA: AP-42	1330	210	766	90	45
Anthracite stokers	Current study	403	ND	ND	ND	4.9
	Existing data	ND	ND	ND	ND	ND
	Combined existing data and current study	403	ND	ND	ND	4.9
	EPA: AP-42	145[d]	145	314	5	nil
Wood stokers	Current study	39	8	ND	20	81
	Existing data	ND	ND	ND	ND	ND
	Combined existing data and current study	39	8	ND	20	81
	EPA: AP-42	215-645	430	65	86-2580	86-3010
Gas-fired reciprocating engines	Current study	0.1	765	ND	450	5
	Existing data	ND	1590	ND	280	380
	Combined existing data and current study	0.1	1535	ND	320	345
	EPA[e]	5	1390	0.26	176	573
Oil-fired reciprocating engines	Current study	42	1083	ND	169	269
	Existing data	14[e]	1360	101	550	320
	Combined existing data and current study	23	1300	101	505	310
	EPA[e]	102	1420	97	312	115

ND - No data.

[a] EPA SO_2 emission factors based on fuel sulfur content of 1.03 percent for bituminous coal and residual oil; 0.24 percent for distillate oil; 0.57 percent for anthracite; and 4,600 g/10^6 Nm^3 for natural gas.

[b] Based on average ash content of 10.25 percent.

[c] All stokers combined to give the following weighted EPA emission factors: Particulates - 133A; NO_x - 210; SO_2 - 743S; CO - 90 and HC - 45 ng/J.

[d] Based on an average ash content of 10 percent.

[e] Data and EPA values from Reference 14. All other EPA emission factors from Reference 24.

The particulate and hydrocarbon emission factor data for the two bituminous, pulverized dry bottom boilers tested are lower than the emission factors published in AP-42. The published EPA emission factor for particulates is 17A pounds of particulate per ton of coal burned, where A is the ash content of the fuel in percent. Uncontrolled emission factors for sites 321 and 343, converted to EPA units, are 13.2A and 5.5A, respectively. The particulate emission factor for controlled site 343 would correspond to the EPA emission factor if the control system were operating at approximately 99.7 percent efficiency, instead of its rated 99 percent efficiency, during the test period.

The emission factor data for the three bituminous stokers tested have been combined in Table 42. The EPA emission factor data shown in the table have been normalized to account for the variations in emission factors resulting from firing method. Analysis of the data for individual sources shows that uncontrolled particulate emission factors of 0.2A, 5.2A, and 2.4A, respectively, were measured in this program for the underfeed, spreader, and overfeed stokers tested. The values are less than the corresponding EPA emission factors of 2A, 13A, and 5A. Agreement with the EPA emission factors for the spreader and overfeed stoker tested would be achieved if the control efficiencies during test were 88 and 86 percent, respectively, instead of their rated 70 percent efficiencies. Particulate emissions from the uncontrolled underfeed stoker tested, however, are a factor of 10 lower than the EPA emission factor. This unit was operated at low heat input rate, a factor that may contribute to the low particulate emissions measured.

Hydrocarbon emission factors for the bituminous stokers tested were also appreciably lower than EPA reported values for the three stoker firing types. The hydrocarbon emission factor for the underfeed stoker, operating at low heat input capacity, was about 12 times lower than the AP-42 value. This discrepancy is somewhat surprising because this source proved to be a large emitter of POM.

Particulate and HC emission factors for the anthracite-fired stokers are higher than those published in AP-42. The data base for particulates must be considered inadequate on the basis of criteria established for this program because of both the variability of the data and the high particulate ambient severity factor. Hydrocarbon emissions from the anthracite stokers, even at the higher levels measured in this program, are not environmentally significant and the data are adequate. Emission factor data for NO_x and CO from all coal-fired sources are too limited to allow meaningful comparisons to be made with EPA emission factors.

Similarly, only one wood-fired stoker was tested (under low load conditions) and valid comparisons with EPA emission factors cannot be made. Noteworthy, however, is the fact that although measured hydrocarbon emissions are slightly less than the lower end of the EPA emission range published in AP-42, POM emissions were large and environmentally significant.

The internal combustion emission factor data obtained in this program were highly variable. The data for gas-fired engines in Table 42 include only the results of the testing at site 349 and do not include the results obtained from dual-fired site 353. The particulate and HC emission factors for site 349 are extremely low in comparison to existing data and EPA emission factors.[14] Although the engine at site 349 is only 1 year old, it is not possible to attribute the low emissions to an age factor on the basis of existing data.[14]

For oil-fired engines, current study emission factors for particulates are appreciably lower than EPA factors, whereas measured CO and HC emission factors are approximately twice as large as the respective EPA values. The values measured in this program, however, are generally in better agreement with the existing data base than the EPA emission factors. The combined program and existing data base emission factors are probably more accurate than EPA values for engines of the size tested in this program.

In summary, the above discussions indicate that (1) in the case of gas- and oil-fired commercial/institutional external combustion sources, the combined existing and current study emission factor data base is adequate and approximately comparable to published EPA emission factors; (2) the data base for solid fuel-fired sources is deficient and more work is needed to resolve differences between the combined data base and published EPA emission factors; (3) the combined data base for oil-fired reciprocating engines of the sizes tested in this study represents the best estimate of emissions from these sources; and (4) the HC data base for gas-, oil- and dual-fired engines is inadequate.

4.3.1.5 Criteria Pollutant Ambient Severity Factors

The significance of the emissions of criteria pollutants from commercial/institutional combustion sources can be assessed using the ambient severity concept. This concept has been discussed in Section 4.1, and detailed methods for the calculation of ambient severity factors are described in Appendix A. Basically, the ambient severity is defined as the ratio of the calculated maximum ground level concentration of the pollutant species to the level at which a potential environmental hazard exists. Ambient severity factors below 0.05 are deemed insignificant.

Ambient severity factors for the criteria pollutants are presented in Table 43. They have been calculated from the emission factors also shown in the table. The emission factors used are best estimates based on analysis of the current study and existing data base for the source categories tested. EPA emission factors are used for many source categories because the combined data from this study and the existing data base are still limited to a comparatively few data points and cannot, as yet, be considered a reliable data base for estimating emissions.

Criteria pollutants of potential concern from gas- and oil-fired boilers are NO_x for all sources and SO_2 for residual oil-fired boilers. For bituminous-, anthracite-, and wood-fired sources, ambient severities for particulates, NO_x, and SO_2 exceed 0.05 and are significant. Hydrocarbon emissions from bituminous and wood stokers are also significant. The severity factors were calculated for typical commercial/institutional size units and represent severity factors for uncontrolled emissions. In the case of the internal combustion units tested, both NOx and HC emissions are of concern. HC emissions from the oil-fired engines are appreciably higher than EPA values, possibly because of the age of the units tested. However, unit age had no apparent effect on HC emissions as measured in a recent study of internal combustion engines.[14]

TABLE 43. CRITERIA POLLUTANT EMISSION FACTORS AND AMBIENT SEVERITY FACTORS[a] FOR COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES

Source category	Pollutant									
	Particulates		NO_x		SO_2		CO		HC	
	Emission factor (ng/J)	Ambient severity factor[b]	Emission factor (ng/J)	Ambient severity factor[b]	Emission factor (ng/J)	Ambient severity factor[b]	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor[b]
Gas-fired boilers	2	0.0007	50	0.08	0.26	< 0.0001	8	< 0.0001	3	0.0026
Distillate oil-fired boilers	6	0.0022	68	0.11	106	0.028	8	< 0.0001	3	0.0026
Residual oil-fired boilers	37	0.014	172	0.28	464	0.12	8	< 0.0001	3	0.0026
Bituminous, pulverized dry bottom boilers	3406	2.6	352	1.2	766	0.42	20	0.0002	6	0.01
Bituminous underfeed stokers	400	0.16	117	0.19	766	0.2	195	0.0008	59	0.05
Anthracite stokers	145	0.05	145	0.24	314	0.08	15	< 0.0001	5	0.004
Wood stokers	215	0.08	10	0.017	65	0.017	100	0.0004	100	0.09
Gas-fired reciprocating engines	5	0.001	1390	1.66	0.26	< 0.0001	300	0.0009	400	0.25
Oil-fired reciprocating engines	40	0.01	1420	1.7	97	0.017	400	0.001	300	0.18

[a] Based on heat input rates of 100 × 10^9 J/hr for pulverized units and 10 × 10^9 J/hr for all other external combustion source categories, a heat input rate of 3.75 × 10^9 J/hr for the internal combustion sources, and sulfur and ash contents as shown in Table 42 for the calculation of emission factors.

[b] Ambient severity factor values underlined are in excess of 0.05.

4.3.2 Particle Size Distribution of Particulate Emissions

Particle size distribution data were determined from the weight collected by the three cyclones and the particulate filter of the SASS train during tests of the solid fuel-fired units. The underfeed stoker, tested with wood as a fuel (site 219) and later with bituminous coal (site 220), and the three anthracite stokers were uncontrolled, whereas one of the pulverized units was equipped with an efficient (99 percent) wet scrubber and the overfeed and spreader stokers were controlled by mechanical collectors of 70 percent rated efficiency. As shown in Table 44, there is a definite decrease in the size of particulates emitted by the controlled pulverized unit. Data for the controlled bituminous stokers show large variabilities indicating a difference in control device performance or in the character of emissions from the source. The percentage of emissions from one bituminous stoker (site 342) in the less than 1 μm particulate fraction is much higher than would be expected downstream of a mechanical collector, indicating that particulate emissions from this unit were extremely fine. Particulate emissions from the underfeed stoker during both the firing of bituminous coal and wood were also much smaller in size than anticipated.

Data variability was calculated for the anthracite stoker data for both emission factors and the percentage of total particulate emissions of the four size fractions measured. Data variability generally exceeded 0.7 with the exception of the percentage of particulate found in the 3 μm and larger fractions.

The particle size distribution data for all the commercial/institutional solid fuel-fired sources tested are inadequate. Because there is no existing particle size data base for these commercial/institutional sources, further testing will be required to build an adequate data base.

4.3.3 Emissions of Particulate Sulfate and SO_3

Emission factors and ambient severity factors for particulate sulfate and SO_3 emissions measured in the test program are presented in Table 45. Particulate sulfate emissions were measured at two of the residual oil-fired boilers tested and at all nine of the solid fuel-fired boilers tested in this study. Particulate sulfate emission factors from the two oil-fired

TABLE 44. PARTICLE SIZE DISTRIBUTION DATA FOR THE SOLID FUEL-FIRED COMMERCIAL/INSTITUTIONAL SOURCES TESTED

Site No.	Control device		Particulate emissions, ng/J (% in size range)				
	Type	Efficiency (%)	< 10 μm	3-10 μm	1-3 μm	< 1 μm	Total
Bituminous, pulverized dry bottom boilers							
321	None	-	1146 (44.8)	931 (36.4)	369 (14.4)	114 (4.5)	2560 (100)
343	Wet scrubber	99	6.9 (47.0)	0.07 (0.5)	3.7 (25.2)	4.0 (27.4)	14.7 (100)
Bituminous stokers							
Underfeed							
220	None	-	0.61 (5.1)	0.17 (1.4)	0.09 (0.75)	11.1 (92.5)	12 (100)
Spreader							
325	Mechanical	70	90.6 (24.8)	144.1 (39.7)	14.1 (3.9)	115.2 (31.6)	365 (100)
Overfeed							
342	Mechanical	70	4.9 (4.6)	9.8 (9.2)	5.0 (4.7)	86.4 (81.5)	106 (100)
Anthracite stokers							
320	None	-	420.0 (78.5)	68.5 (12.8)	22.5 (4.2)	24.6 (4.6)	535 (100)
344	None	-	386.5 (77.0)	52.2 (10.4)	9.0 (1.8)	54.8 (10.9)	502 (100)
345	None	-	107.7 (63.0)	27.0 (15.8)	4.1 (2.4)	32.1 (18.8)	171 (100)
		$\bar{x}$	304.7 (72.8)	49.2 (13.0)	11.9 (2.8)	37.2 (11.4)	403 (100)
		$s(\bar{x})$	99 (4.9)	12.1 (1.6)	5.5 (0.72)	9.1 (4.1)	116 (100)
		$ts(\bar{x})/\bar{x}$	1.39 (0.29)	1.06 (0.52)	2.0 (1.11)	1.05 (1.55)	1.2 (100)
Wood stokers							
Underfeed							
219	None	-	5.2 (13.3)	0.72 (1.8)	0.74 (1.9)	32.5 (83.3)	39 (100)

TABLE 45. PARTICULATE SULFATE AND SO_3 EMISSION FACTORS AND AMBIENT SEVERITY FACTORS FOR THE COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES TESTED

Source category	Site No.	Flue gas excess air (%)	Particulate sulfate		SO_3	
			Emission factor (ng/J)	Ambient severity factor[a]	Emission factor (ng/J)	Ambient severity factor[a]
Residual oil-fired boilers	120	30	< 0.03	< 0.001	-	-
	124	50	< 0.03	< 0.001	-	-
Bituminous, pulverized dry bottom boilers	321	120	2.9	0.17	1.0	0.07
	343	51	1.2	0.07		
Bituminous stokers	220	105	1.4	0.04	-	-
	325	290	7.8	0.22	12.1	0.44
	342	49	1.4	0.04	-	-
Anthracite stokers	320	260	4.7	0.13	19.3	0.7
	344	425	57	1.6	-	-
	345	235	20	0.6	-	-
Wood-fired stokers	219	150	3.5	0.10	-	-

[a] Based on a fuel firing rate of 100×10^9 J/hr for pulverized units; 10×10^9 J/hr for all other combustion source categories.

sites tested (sites 120 and 124) were both less than 0.03 ng/J, corresponding to a percent conversion of fuel sulfur to particulate sulfate of less than 0.03 percent. This conversion is appreciably lower than the value of 1 percent or greater reported in one study[26] but is consistent with low particulate sulfate values obtained in a study of industrial boiler emissions.[23]

Conversions of fuel sulfur to particulate sulfate as measured in this study were 0.2, 0.3, and 3.9 percent for bituminous, pulverized dry bottom boilers, bituminous stokers, and anthracite stokers, respectively. Approximately 0.7 percent conversion was found in tests of utility boilers.[28] There does appear to be an approximate correlation between percent conversion and flue gas excess air. Percent excess air values in the flue gases of the anthracite stokers were all in excess of 200 percent, probably indicating excessive air leakage into the system before emission from the stack. Particulate sulfate emissions from the wood-fired boiler tested represent either a high percent conversion of fuel sulfur to particulate sulfate or the emission of natural sulfates in the wood fuel.

The emissions of SO_3 were measured using controlled condensation procedures at sites 321 (bituminous, pulverized), 325 (bituminous stoker), and 320 (anthracite stoker). Percent conversions of fuel sulfur to SO_3 were 0.08, 1.7, and 2.3 percent, respectively. Corresponding conversions to particulate sulfate were 0.2, 1.11, and 0.6 percent. Overall, the data for emissions of primary sulfate (particulate sulfate and SO_3) are highly variable and seem to be somewhat dependent on flue gas oxygen content. The data base must be considered inadequate on the basis of criteria established for this program because emissions of SO_3 from the bituminous and anthracite sources tested are associated with ambient severity factors greater than 0.05.

Emissions of SO_3 from wood-fired boilers, although not measured, would appear to be of lesser significance because of the low sulfur content of wood fuel.

4.3.4 Emissions of Trace Elements

Trace element emissions from solid fuel-fired combustion sources were determined from analysis of the collected SASS train samples, and emission factors calculated from the SASS data using the techniques described in Appendix B. However, emission factors for oil-fired sources were calculated from analysis of the fuel feed, assuming total release of the elements to the flue gas. Trace element emissions from gas-fired sources were not measured in this program. SSMS was the principal analytical procedure used for the measurement of trace element emissions, with values for mercury determined by AAS. Specific AAS analyses for arsenic and antimony, collected by the APS impingers, were conducted when certain criteria, as described in Section 4.1, were met.

4.3.4.1 Oil-Fired Combustion Sources

Trace element emission factors, variabilities, and ambient severity factors for the three distillate and five residual oil-fired units tested are shown in Table 46. The data variability exceeds 0.7 for all but a few elements, reflecting differences in the trace element content of the fuels and also the limited data base. As noted above, the emission factors are based on SSMS analyses of the fuels burned at those sites and on the assumption that all elements exit with the flue gas. Despite the general variability of the data, it is apparent from Table 46 that only a very few elements emitted by the oil-fired sources are of potential environmental significance. Trace element emissions from residual oil-fired sources, as expected, are of slightly greater significance than those from distillate oil-fired sources. Only nickel from distillate oil sources, and nickel and chromium from residual oil sources have ambient severities exceeding 0.05, the level at which emissions are deemed environmentally significant. Based on the results of this study, the data base for these elements must be considered inadequate.

A comparison of current study trace element emission factors with existing data is provided in Table 47. Elements listed are those with high ambient severity factors as determined from the emission factor data in Table 46.

TABLE 46. TRACE ELEMENT EMISSION FACTORS AND AMBIENT SEVERITY FACTORS[a] FOR THE DISTILLATE AND RESIDUAL OIL-FIRED COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES TESTED

	Distillate oil-fired boilers				Residual oil-fired boilers			
Trace element	Mean emission factor $\bar{X}$ (pg/J)	$\frac{ts(\bar{X})}{\bar{X}}$	Mean ambient severity factor	Upper limit ambient severity factor	Mean emission factor $\bar{X}$ (pg/J)	$\frac{ts(\bar{X})}{\bar{X}}$	Mean ambient severity factor	Upper limit ambient severity factor
Aluminum (Al)	15	2.3	< 0.0001	0.0002	156	1.7	0.0009	0.0024
Arsenic (As)	1.3	1.8	< 0.0001	0.0002	9.1	2.6	0.0005	0.0018
Boron (B)	2.0	6.3	< 0.0001	0.0003	8.3	ID	< 0.0001	-
Barium (Ba)	8.4	1.2	0.0005	0.0015	9.5	1.8	0.0006	0.0023
Beryllium (Be)	0.038	ID	0.0005	-	0.065	ID	0.0009	-
Bromine (Br)	9.1	1.6	< 0.0001	0.0002	0.46	ID	< 0.0001	-
Calcium (Ca)	845	ID	0.0056	-	780	2.4	0.0050	0.0230
Cadmium (Cd)	2.5	ID	0.0014	-	0.2	ID	0.0001	-
Cobalt (Co)	2.3	0.41	0.0013	0.0022	23	1.9	0.0133	0.0386
Chromium (Cr)	36	1.4	0.0104	0.025	50	2.5	0.0144	0.0504
Copper (Cu)	205	1.2	0.0059	0.0130	93	1.1	0.0028	0.0059
Fluorine (F)	14	3.6	< 0.0001	0.0002	85	1.0	0.0003	0.0006
Iron (Fe)	545	2.0	0.0032	0.0090	379	2.1	0.0022	0.0068
Mercury (Hg)	1.7	0.29	0.0010	0.0013	1.9	1.7	0.0011	0.0030
Potassium (K)	60	3.6	0.0009	0.0040	213	1.4	0.0031	0.0074
Lithium (Li)	1.5	ID	0.0020	-	1.0	1.9	0.0013	0.0038
Magnesium (Mg)	40	0.90	0.0001	0.0002	111	1.2	0.0003	0.0007
Manganese (Mn)	6.1	0.71	< 0.0001	0.0001	52	2.4	0.0003	0.0010
Molybdenum (Mo)	16	1.2	0.0001	0.0002	63	ID	0.0010	-
Sodium (Na)	101	2.3	< 0.0001	0.0002	418	0.96	0.0022	0.0005
Nickel (Ni)	112	3.4	0.0324	0.1426	804	2.0	0.2326	0.6978
Phosphorus (P)	5.7	1.6	0.0002	0.0004	107	2.3	0.0031	0.0102
Lead (Pb)	48	0.9	0.009	0.017	7	ID	0.0001	-
Antimony (Sb)	1.7	1.4	< 0.0001	0.0002	2.9	ID	0.0022	-
Selenium (Se)	2.7	0.6	0.0004	0.0006	1.1	ID	0.0002	-
Silicon (Si)	173	1.33	0.0005	0.0012	1610	1.7	0.0047	0.0127
Tin (Sn)	2.1	1.2	< 0.0001	< 0.0001	1.3	ID	< 0.0001	-
Strontium (Sr)	9.7	0.74	< 0.0001	0.0002	0.91	0.78	< 0.0001	< 0.0001
Thorium (Th)	LB	-	-	-	LB	-	-	-
Uranium (U)	LB	-	-	-	LB	-	-	-
Vanadium (V)	30	0.85	0.0002	0.0004	250	2.8	0.0014	0.0055
Zinc (Zn)	40	2.8	0.0002	0.0009	46	0.92	0.0003	0.0006

[a] Based on a heat input rate of 10 × 10^9 J/hr.

ID = Insufficient data for calculation of variability.

LB = Lower than Blank Value.

TABLE 47. COMPARISON OF EXISTING TRACE ELEMENT EMISSION FACTOR DATA WITH RESULTS OF CURRENT STUDY OF OIL-FIRED COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES, pg/J

	Distillate oil-fired boilers		Residual oil-fired boilers		
		Existing data		Existing data	
Element	Current study	Ref. 11	Current study	Ref. 27	Ref. 28
Aluminum (Al)	15	250	156	87	132
Arsenic (As)	1.3	1.5	9.1	18	12
Barium (Ba)	8.4	16	9.5	29	31
Calcium (Ca)	845	450	780	320	1,428
Cadmium (Cd)	2.5	11	0.2	52	6.9
Cobalt (Co)	2.3	1.0	23	50	10
Chromium (Cr)	36	29	50	30	21
Copper (Cu)	205	160	93	64	350
Fluorine (F)	14	-	85	2.7	149
Iron (Fe)	545	140	379	411	453
Mercury (Hg)	1.7	1.2	1.9	0.9	1.5
Potassium (K)	60	230	213	777	392
Lithium (Li)	1.5	1.2	1.0	1.4	1.7
Magnesium (Mg)	40	210	111	297	2,384
Nickel (Ni)	112	290	804	964	433
Lead (Pb)	48	42	7	80	34
Antimony (Sb)	1.7	5.7	21	10	25
Silicon (Si)	173	-	1,610	400	595
Vanadium (V)	30	2.9	250	3,656	714
Zinc (Zn)	40	110	46	29	66

The referenced data for distillate oil represent emission factors measured in a recent study of emissions from seven residential combustion sources.[11] Because residential source emission factors were also calculated from fuel concentrations as determined by SSMS, differences between the current study and the residential study data should be attributable to the trace element content of the fuels used in the two studies. Reasonable agreement is shown for approximately two-thirds of the 18 elements listed in the table. Emission factors for the remaining elements differ by more than a factor of 3. However, ambient severity factors calculated from both the existing study and the residential study emission factor data are less than 0.05 for all elements with the exception of nickel.

In the case of the residual oil-fired sources, the current study data base is compared with data that represent the weighted nationwide trace element content of residual oils and recent trace element emissions data for utility boilers. Reasonable agreement of the current study data base with the existing data base is shown for 13 of the 18 elements. The use of the highest emission factor value from the three data sources in Table 47 increases the calculated ambient severity factors shown in Table 46 to a value greater than 0.05 for cobalt, magnesium, and vanadium.

In summary, the trace element emission data base is inadequate for nickel emitted from distillate oil-fired combustion sources and for nickel, chromium, cobalt, magnesium, and vanadium emitted from residual oil-fired sites. Other elements, namely, chromium and copper from distillate oil-fired sources, and calcium, copper, potassium, phosphorus, and silicon from residual oil-fired sources, may be of environmental concern because the range of variability of these elements in oil fuels is unknown.

4.3.4.2 Solid Fuel-Fired Combustion Sources

As noted previously in Section 4.1, existing trace element emission factor data for commercial/institutional solid fuel-fired combustion sources are extremely limited. Further, interpretation of the current study and existing data base is difficult because of the large variations in fuel, control device performance, and other factors related to the combustion source and its operation.

Emission factors and ambient severity factors for the bituminous-fired combustion sources tested in this program are shown in Table 48. The units tested were two pulverized dry bottom units, one uncontrolled and the other controlled by a wet scrubber of 99 percent efficiency; and three stokers, an uncontrolled underfeed stoker and an overfeed and spreader stoker, the last two controlled by mechanical precipitators of 70 percent rated efficiency. The ambient severity factors were calculated from the emission factor data using the heat input rates specified in the table.

Ambient severity factors calculated for trace element emissions from the uncontrolled dry bottom boiler are generally greater than 0.05. Beryllium, lithium, and phosphorus severity factor values are greater than 1.0. Chlorine emissions, although not shown in Table 48, could be associated with severity factors greater than 1.0 on the basis of existing data shown in Table 17. Other elements with severity factors greater than 0.05 are barium, cobalt, chromium, magnesium, and nickel. However, only nickel emissions from the controlled dry bottom unit are associated with an ambient source severity factor greater than 0.05. The control device, rated at 99 percent efficiency, may well have operated at the 99.7 percent level based on a comparison of its measured particulate emission factor (109A ng/J) with the EPA AP-42 emission factor (332A ng/J). An obvious conclusion to be drawn from the emission data for pulverized dry bottom sources is that trace element emissions from uncontrolled sources are of environmental significance. Emissions of certain elements (e.g., nickel emissions from site 343) may also be significant even for a well-controlled source operating at the proposed NSPS emission level of ~ 0.03 lb/10^6 Btu (13 ng/J) for utility boilers.

The data for the stoker-fired sources tested indicate that (1) emissions from an underfeed stoker, with the exception of phosphorus emissions, do not represent an environmental problem; (2) emissions from a particulate controlled (70 percent efficiency) spreader stoker are significant for the elements phosphorus, iron, beryllium, calcium, and lithium (ambient severity

TABLE 48. TRACE ELEMENT EMISSION FACTORS AND AMBIENT SEVERITY FACTORS FOR THE BITUMINOUS-FIRED COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES TESTED

Element	Bituminous, pulverized dry bottom				Bituminous stokers					
	Site 321		Site 343[a]		Underfeed, Site 220		Spreader, Site 325[a]		Overfeed, Site 342[a]	
	Emission factor (pg/J)	Ambient severity factor[b]	Emission factor (pg/J)	Ambient severity factor[b]	Emission factor (pg/J)	Ambient severity factor[b]	Emission factor (pg/J)	Ambient severity factor[b]	Emission factor (pg/J)	Ambient severity factor[b]
Aluminum (Al)	27,500	0.323	1,100	0.013	53	< 0.001	2,821	0.041	8,250	0.046
Arsenic (As)	1,925	0.235	22	0.003	1.8	< 0.001	5	0.010	11	< 0.001
Boron (B)	3,355	0.066	41	< 0.001	1.9	< 0.001	52	0.001	26	< 0.001
Barium (Ba)	4,235	0.517	63	0.008	0.54	< 0.001	319	0.049	10	< 0.001
Beryllium (Be)	132	4.026	0.41	0.013	LB	-	3.4	0.130	0.33	0.005
Bromine (Br)	14	< 0.001	3.7	< 0.001	0.38	< 0.001	1.8	< 0.001	2.6	< 0.001
Calcium (Ca)	40,700	0.497	274	0.003	50	< 0.001	6,188	0.094	102	< 0.001
Cadmium (Cd)	5.5	0.007	0.15	< 0.001	LB	-	2.4	0.004	0.53	< 0.001
Cobalt (Co)	430	0.534	2.2	0.003	0.26	< 0.001	9.1	0.014	22	0.012
Chromium (Cr)	825	0.563	7.8	0.005	8.1	< 0.002	43	0.033	792	0.229
Copper (Cu)	605	0.037	12	< 0.001	2.2	< 0.001	79	0.006	66	0.002
Fluorine (F)	3,245	0.079	10	< 0.001	1.9	< 0.001	318	0.010	0.76	< 0.001
Iron (Fe)	16,500	0.201	666	0.008	76	< 0.001	13,650	0.209	2,840	0.016
Mercury (Hg)	2.5	0.003	0.47	< 0.001	0.18	< 0.001	0.60	< 0.001	5.6	0.003
Potassium (K)	10,500	0.320	207	0.006	9.2	< 0.001	1,274	0.049	330	0.005
Lithium (Li)	1,155	3.203	0.45	0.001	0.16	< 0.001	18	0.063	1.1	0.001
Magnesium (Mg)	41,800	0.510	48	< 0.001	7.0	< 0.001	291	0.004	5.0	< 0.001
Manganese (Mn)	1,155	0.014	11	< 0.001	1.5	< 0.001	81	0.001	125	< 0.001
Molybdenum (Mo)	94	0.001	36	< 0.001	1.5	< 0.001	8.2	< 0.001	139	< 0.001
Sodium (Na)	20,350	0.248	159	0.002	7.0	< 0.001	346	0.005	1,137	0.007
Nickel (Ni)	1,045	0.637	133	0.081	13	0.004	39	0.030	660	0.191
Phosphorus (P)	4,675	2.852	63	0.038	330	0.095	2,640	2.017	363	0.104
Lead (Pb)	360	0.146	5.2	0.002	5.7	0.001	60	0.031	32	0.006
Antimony (Sb)	50	0.006	0.55	< 0.001	0.22	< 0.001	2.9	< 0.001	0.76	< 0.001
Selenium (Se)	40	0.012	22	0.006	0.76	< 0.001	LB	-	11	0.002
Silicon (Si)	78,000	0.476	1,960	0.012	97	< 0.001	4,004	0.031	693	0.002
Tin (Sn)	37	< 0.001	1.3	< 0.001	5.2	< 0.001	8.5	< 0.001	5.6	< 0.001
Strontium (Sr)	4,235	0.081	27	< 0.001	11	< 0.001	819	0.020	9.6	< 0.001
Thorium (Th)	LB	-	0.22	< 0.001	LB	-	4.7	< 0.001	0.36	< 0.001
Uranium (U)	LB	-	0.52	< 0.001	LB	-	1.0	< 0.001	3.3	< 0.001
Vanadium (V)	1,375	0.167	8.9	0.001	8.1	< 0.001	25	0.004	5.9	< 0.001
Zinc (Zn)	1,760	0.027	26	< 0.001	3.6	< 0.001	60	0.001	33	< 0.001

[a] Controlled boiler: control efficiency is 99 percent for Site 343 and 70 percent for Sites 325 and 342.

[b] Based on a heat input rate of 100 × 10^9 J/hr for the pulverized dry bottom boiler; 50 × 10^9 J/hr for the spreader stoker; and 10 × 10^9 J/hr for other stokers.

LB = Lower than blank value.

factors greater than 0.05); and (3) emissions from a particulate controlled (70 percent efficiency) overfeed stoker are significant for the elements chromium, nickel, and phosphorus (ambient severity factors greater than 0.05). However, because of fuel trace element variations and other factors, it is difficult to draw firm conclusions regarding the environmental significance of trace element emissions on the basis of the limited test data. The underfeed stoker tested, for example, was burning a low ash content fuel (3.84 percent) and operating at a low load factor of 41 percent during the test period. The measured particulate emission factor of 3.1A is well below the AP-42 emission factor of 39A. Thus, this boiler was emitting less than 10 percent of the average particulate emissions from underfeed stokers, according to data sources used to compile the particulate emission factor for AP-42.

The existing data previously presented in Table 17 for bituminous, pulverized dry bottom units and underfeed stokers may represent a more accurate appraisal of emissions and ambient severity factors than the data shown in Table 48 which are based on one test of these combustion source categories. This is particularly true in the case of the underfeed stoker source because of the low ash content and low load conditions during the test. Data in Table 17 indicate that control devices with efficiencies of approximately 97 percent for pulverized units and 50 percent for stokers are required to reduce ambient severity factors for all particulate trace elements to below 0.05 for these sources. This analysis is based on average fuel trace element contents and contains no safety factor to account for fuel and combustion source variability.

Trace element emission factors and calculated ambient severity factors are presented in Table 49 for three uncontrolled anthracite stokers and one uncontrolled wood-fired underfeed stoker. The variability of the emission factor data for the three anthracite stokers tested is also shown in Table 49. Calculated variabilities exceed 0.7 for all but one element and, therefore, upper limit ambient severity factors, as defined in Appendix A, were used to assess the environmental significance of the trace element emissions from anthracite stokers. Elements associated with ambient severity factors greater than 0.05 are phosphorus, aluminum, chromium, lithium, nickel, silicon, and

TABLE 49. TRACE ELEMENT EMISSION FACTORS AND AMBIENT SEVERITY FACTORS[a] FOR THE ANTHRACITE- AND WOOD-FIRED COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES TESTED

	Anthracite stokers							Wood stokers	
Trace element	Emission factor (pg/J)			Mean $\bar{X}$ (pg/J)	$\frac{ts(\bar{X})}{\bar{X}}$	Mean ambient severity factor	Upper limit ambient severity factor	Emission factor (pg/J)	Mean ambient severity factor
	Site 320	Site 344	Site 345					Site 219	
Aluminum (Al)	21,840	40,500	26,180	29,506	0.82	0.163	0.298	31	< 0.001
Arsenic (As)	2.3	101	73	66	1.5	0.004	0.010	0.34	< 0.001
Boron (B)	23	2,700	62	932	4.1	0.009	0.044	13	< 0.001
Barium (Ba)	229	567	39	278	2.4	0.016	0.055	10	< 0.001
Beryllium (Be)	9.4	4.6	0.4	4.8	2.3	0.072	0.236	LB	-
Bromine (Br)	16	120	10	49	3.1	< 0.001	< 0.001	3.4	< 0.001
Calcium (Ca)	853	1,107	655	872	0.64	0.005	0.008	627	0.004
Cadmium (Cd)	1.0	1.5	0.6	1.0	1.2	< 0.001	0.001	0.29	< 0.001
Cobalt (Co)	35	36	13	28	1.2	0.016	0.035	1.1	< 0.001
Chromium (Cr)	102	648	377	376	1.8	0.109	0.304	4.0	0.002
Copper (Cu)	114	311	100	175	2.5	0.005	0.018	3.8	< 0.001
Fluorine (F)	125	621	65	270	2.8	0.003	0.012	15	< 0.001
Iron (Fe)	4,050	10,935	3,003	5,996	1.8	0.034	0.097	205	0.001
Mercury (Hg)	3.0	1.5	2.3	2.3	0.8	0.001	0.002	0.51	< 0.001
Potassium (K)	801	5,535	2,233	2,856	2.1	0.041	0.128	1,482	0.021
Lithium (Li)	80	149	7.8	79	2.2	0.104	0.332	1.0	0.001
Magnesium (Mg)	354	945	223	507	1.9	0.003	0.008	41	< 0.001
Manganese (Mn)	17	70	59	49	1.4	< 0.001	< 0.001	14	< 0.001
Molybdenum (Mo)	18	189	37	81	2.9	< 0.001	0.002	2.1	< 0.001
Sodium (Na)	146	830	1,500	825	2.0	0.005	0.014	24	< 0.001
Nickel (Ni)	135	459	470	355	1.3	0.102	0.236	3.6	0.001
Phosphorus (P)	322	4,185	1,540	2,016	2.4	0.578	1.965	137	0.039
Lead (Pb)	70	189	116	125	1.2	0.024	0.053	9.1	0.002
Antimony (Sb)	28	12	8.5	7.8	1.5	< 0.001	0.001	0.24	< 0.001
Selenium (Se)	20	28	6.2	37	1.5	0.005	0.013	1.5	< 0.001
Silicon (Si)	20,800	28,350	52,360	33,836	1.2	0.098	0.215	1,026	0.003
Tin (Sn)	12	27	12	17	1.3	< 0.001	< 0.001	5.1	< 0.001
Strontium (Sr)	56	92	25	58	1.4	< 0.001	0.001	0.1	< 0.001
Thorium (Th)	0.3	4.6	0.4	1.8	5.9	< 0.001	< 0.001	LB	-
Uranium (U)	0.6	3.6	0.8	1.7	4.2	< 0.001	0.002	LB	-
Vanadium (V)	60	74	377	170	2.6	0.010	0.035	0.17	< 0.001
Zinc (Zn)	87	972	193	417	2.9	0.003	0.012	39	< 0.001

[a] Based on a heat input rate of 10 × 10^9 J/hr.

LB = Lower than Blank Value.

beryllium. The data base must be considered inadequate for these elements and, on the basis of data presented in Table 17, for other elements, particularly chlorine, as well. Emission factors shown in Table 17 were developed from anthracite fuel trace element content data, Reference 28, and AP-42 emission factors.[24] Because the trace element fuel content variability is unknown, all of the elements noted above, and possibly other elements, may be environmentally significant. A control device with an efficiency of about 91 percent would be required to reduce the ambient severity factor for phosphorus (the element with the highest severity factor in Table 49) to a level below 0.05.

Only one wood-fired combustion source, an underfeed stoker, was tested. This unit was operated at low load, approximately 40 percent, during the test period. The low emissions (particulate emission factor of 39 ng/J versus the EPA AP-42 emission factor of 215 to 645 ng/J) and the low ambient severity factors (all elements less than 0.05) may not be representative of other wood-fired units.

In summary, all solid fuel-fired combustion sources with source parameters representative of commercial/institutional systems would appear to require some application of control to reduce trace element ambient severity factors to acceptable levels. However, more data are needed to determine trace element emissions and associated ambient severity factors for solid fuel-fired commercial/institutional combustion sources.

4.3.4.3 Oil-Fired Reciprocating Engines

Trace element emission factors and ambient severity factors for the oil-fired reciprocating engines tested are presented in Table 50. The ambient severity factors are based on the average heat input rate of the units tested (3.8×10^9 J/hr). Trace element emissions from medium-size reciprocating engines are not of environmental significance. The trace element emission data base is adequate for these sources and no further testing is needed.

TABLE 50. TRACE ELEMENT EMISSION FACTORS AND AMBIENT SEVERITY FACTORS[a] FOR THE COMMERCIAL/INSTITUTIONAL OIL-FIRED RECIPROCATING ENGINES TESTED

Trace element	Emission factor (pg/J) Site 329	Site 347	Site 348	Site 350	Mean $\bar{X}$ (pg/J)	$\frac{ts(\bar{X})}{\bar{X}}$	Mean ambient severity factor
Aluminum (Al)	288	LB	LB	LB	72	-	< 0.001
Arsenic (As)	1.3	LB	LB	0.33	0.41	-	< 0.001
Boron (B)	1.3	1.3	0.6	0.33	0.88	0.6	< 0.001
Barium (Ba)	8.0	12	2.4	20	11	1.1	< 0.001
Beryllium (Be)	LB	LB	LB	LB	LB	-	-
Bromine (Br)	4.7	LB	LB	LB	1.2	-	< 0.001
Calcium (Ca)	114	107	120	85	107	0.23	< 0.001
Cadmium (Cd)	4.4	LB	LB	LB	1.1	-	0.002
Cobalt (Co)	0.67	0.23	0.5	0.52	0.48	0.61	< 0.001
Chromium (Cr)	6.0	6.5	6.0	5.8	6.1	0.08	0.001
Copper (Cu)	141	299	120	137	174	0.76	0.004
Fluorine (F)	LB	LB	LB	LB	LB	-	-
Iron (Fe)	174	46	30	189	110	1.2	< 0.001
Mercury (Hg)	LB	1.1	1.3	1.8	1.1	0.67	< 0.001
Potassium (K)	395	99	40	42	144	1.9	0.001
Lithium (Li)	LB	LB	0.48	0.2	0.2	-	< 0.001
Magnesium (Mg)	87	14	40	16	39	1.4	< 0.001
Manganese (Mn)	6.0	2.6	2.4	2.6	3.4	0.81	< 0.001
Molybdenum (Mo)	LB	LB	LB	0.8	0.2	-	< 0.001
Sodium (Na)	LB	53	156	63	68	1.5	< 0.001
Nickel (Ni)	LB	34	13	14	15	1.5	0.003
Phosphorus (P)	LB	7.8	30	9.1	12	1.9	0.002
Lead (Pb)	16	2.6	16	8.5	11	0.94	0.002
Antimony (Sb)	LB	LB	LB	LB	LB	-	-
Selenium (Se)	LB	LB	LB	0.20	0.05	-	< 0.001
Silicon (Si)	LB	1560	432	845	709	1.5	0.002
Tin (Sn)	4.7	LB	LB	0.91	2.8	-	< 0.001
Strontium (Sr)	2.7	0.9	2.4	0.52	1.6	1.1	< 0.001
Thorium (Th)	LB	LB	LB	LB	LB	-	-
Uranium (U)	LB	LB	LB	LB	LB	-	-
Vanadium (V)	4.7	3.9	3.6	3.3	3.9	0.25	< 0.001
Zinc (Zn)	38	29	50	52	42	0.41	< 0.001

[a] Based on an average heat input rate of 3.75×10^9 J/hr.

LB = Lower than Blank Value.

4.3.5 Emissions of Organics and POM

Analyses of organic emissions from the commercial/institutional sources tested indicate that the principal constituents are alcohols/glycols, esters, carboxylic acids, naphthalenes, and saturated aliphatic hydrocarbons. The most prevalent species have relatively high MATE values, in the range of 10 to 1100 mg/m^3. Mean ambient severity factors based on these MATE values indicate that emissions of specific organics, excluding POM, from all the commercial/institutional sources tested are not significant. Calculated ambient severity factors are all less than 0.05.

POM emission factors and ambient severity factors for the underfeed stoker tested during the program are presented in Table 51. This stoker unit was tested twice, first during wood firing (designated site 219) and again during bituminous coal firing (designated site 220). For both tests, the unit was operated at low heat input levels, and in both tests, significant quantities of POM compounds were emitted. Because it was not possible in certain cases to positively identify compounds or isomers of similar molecular weight by GC/MS analysis, the procedure used to determine ambient severity factors was to sum the contribution of the compounds and/or isomers and to assume that the POM was the one with the lowest MATE value. Thus, the compounds shown in the table and their associated severity factors represent worst-case conditions. Active carcinogens shown in the table, such as benzo(a)pyrene and benzo(g,h,i)perylene, were not positively identified, and Level II analysis would be required for confirmation. However, at least one active carcinogen; i.e., dibenzo(a,h)anthracene, was identified and emissions of this compound during the test period indicate a potential hazard.

POM emission factors and their associated ambient severity factors were not significant in the case of the other external combustion sites tested. Naphthalene, at low levels, was the principal POM compound emitted from these sources. Only one gas-fired boiler (Site 333) emitted compounds such as phenanthrene, fluoranthene, and pyrene (see Table 38). Low excess air operation (~ 10 percent) may account for the relatively high POM emissions from this site. However, ambient severity factors were below 0.001 for all POM compounds emitted from these sources.

TABLE 51. POM EMISSION FACTORS AND AMBIENT SEVERITY FACTORS FOR THE COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES TESTED

POM compound	MATE value (mg/m^3)	Bituminous, underfeed stoker, site 220		Wood, underfeed stoker, site 219	
		Emission factor (pg/J)	Ambient severity factor	Emission factor (pg/J)	Ambient severity factor
Naphthalene	50	187	< 0.001	3448	0.002
Biphenyl	1.0	-	-	1084	0.031
Fluorene	14	-	-	930	0.002
Phenanthrene	1.6	289	0.005	4457	0.080
Methyl phenanthrene	30	38	< 0.001	1032	< 0.001
Phenyl naphthalene[a]	50	-	-	652	< 0.001
Fluoranthene	90	247	< 0.001	2261	< 0.001
Pyrene	230	249	< 0.001	2460	< 0.001
Methyl pyrene	230	48	< 0.001	737	< 0.001
Benzo(g,h,i)fluoranthene[b]	0.9	-	-	1214	0.039
Chrysene	2.2	22	< 0.001	524	0.007
Benzo(a)anthracene	0.045	132	0.085	-	-
Benzo(a)pyrene	0.00002	178	257	3562	5147
Benzo(g,h,i)perylene[c]	0.2	48	0.007	2410	0.348
Dibenzo(a,h)anthracene	0.00009	25	8.0	393	126
Dibenzo(a,i)pyrene	0.043	26	0.011	677	0.455
Benzo(c)fluoranthene[b]	0.9	-	-	219	0.007
Methyl benzo(a)-anthracene[d]	0.00026	12	1.3	239	37

[a] The MATE value for naphthalene is used.

[b] The MATE value for benzo(e)fluoranthene is used.

[c] The TLV for particulate polycyclic aromatic hydrocarbons is used.

[d] The MATE value for 7,12-dimethyl benzo(a)anthracene is used.

POM emissions and severity factors were somewhat higher for the dual- and oil-fired internal combustion sites tested. Although naphthalene and its derivatives were the principal constituents emitted, other compounds such as biphenyl and phenanthrene were identified. Severity factors were less than 0.01, however, for all compounds identified.

In view of the high ambient severity factors found for POM emissions from sites 219 and 220, additional testing is warranted. Positive identification of active carcinogens will require Level II GC/MS analysis. The influence of heat input level should also be investigated in more detail. As noted above, these sites were operated at low heat input level, implying lower than normal temperatures and possibly inefficient combustion, factors that appear to favor POM compound formation. It is worth noting that the POM data obtained by the Public Health Service[25] did appear to indicate that high POM emissions were associated with low load operations. Operation of solid fuel-fired units at low load levels or in an on/off mode is not uncommon for small combustion sources, and the impact of such operational modes on the emission of POM compounds requires further study.

5.0 TOTAL EMISSIONS

Based on the results of program sampling and analysis efforts and the existing emissions data base, estimates of current nationwide emissions and projected 1985 nationwide emissions from commercial/institutional combustion sources have been made using current and predicted future fuel consumption rates.

5.1 CURRENT AND FUTURE FUEL CONSUMPTION

Fuel consumption data for 1978 for the commercial/institutional sector were obtained from a number of DOE reports, Bureau of Mines publications, and trade journals. Information provided by these sources was synthesized to obtain the fuel consumption estimates presented in Table 52 for the source categories studied in this program. The commercial/institutional sector in 1978 consumed about 10 percent of the total fuel used by stationary combustion sources. In 1978, 44 percent of the fuel consumed by the commercial/institutional sector was natural gas, 24 percent was distillate oil, and 28 percent was residual oil. Solid fuel consumption accounted for the remaining 4 percent (2.3 percent coal and 1.7 percent wood fuel).

Estimates of fuel consumption in 1985 predict a modest increase (~20 percent) in coal and wood consumption based largely on increased sales of small solid fuel burning equipment.[11] The use of oil will decline by 8 percent and the use of natural gas will increase by 16 percent. Overall, fuel use by the commercial/institutional sector will increase 4 percent from 1978 to 1985.

The projection of trends in fuel consumption is subject to large uncertainties and is dependent upon future regulatory and national policy decisions and international events that can significantly affect future fuel consumption patterns. At present, firm data regarding the operation of boilers in the commercial/institutional sector are very limited as is information concerning the future availability of fuels and combustion equipment. The projected

TABLE 52. 1978 AND PROJECTED 1985 COMMERCIAL/INSTITUTIONAL FUEL CONSUMPTION

Source category	Fuel consumption (10^{15} joules) 1978	1985	% change 1978-1985
Commercial/Institutional	5,090	5,300	+4
External Combustion	5,040	5,245	+4
Coal	140	160	+14
Bituminous	90	109	+21
Pulverized Dry	20	24	+20
Pulverized Wet	1	1	0
All Stokers	70	85	+21
Anthracite[a]	50	50	0
Lignite[a]	<1	<1	0
Petroleum	2,600	2,400	-8
Residual Oil	1,400	1,300	-7
Distillate Oil	1,200	1,100	-8
Natural Gas	2,200	2,565	+16
Refuse (Wood/Bark)	100	120	+20
Internal Combustion	50	55	+10
Petroleum	25	25	0
Natural Gas	25	30	+20

[a] Stoker firing only.

Source: Reference 2, 5, and 8.

modest increase in the use of coal and wood may not materialize because increased coal use by utilities and large industrial sources could divert supplies of natural gas and oil to the commercial/institutional sector. Increased use of coal or wood by commercial/institutional combustion sources also faces certain significant obstacles including the need for fuel storage areas and possibly the cost and availability of small-size combustion equipment.

5.2 NATIONWIDE EMISSIONS

The total nationwide emissions of criteria pollutants from commercial/institutional combustion sources were determined based on combined current study and existing data emission factors (see Table 43) and the estimated 1978 fuel consumption rates shown in Table 52. Nationwide emission totals for the criteria pollutants are presented in Table 53.

The data presented in Table 53 represent uncontrolled emissions. Although this is a realistic portrayal of emissions from gas- and oil-fired sources, some degree of particulate control is applied to the solid fuel-fired combustion sources. It is estimated, based on data in NEDS, that the average particulate control efficiency is 40 percent for bituminous, pulverized dry bottom units and 20 percent for the remaining solid fuel-fired source categories. Control measures for pollutants other than particulates are not applied in the commercial sector, regardless of the fuel burned.

Gas and oil consumption, which represents 96 percent of the fuel used, accounts for 96 percent of the NO_x, 89 percent of the SO_2, 69 percent of the CO, and 69 percent of the HC emitted by commercial/institutional combustion sources. Although solid fuel-fired combustion sources account for 72 percent of uncontrolled particulate emissions, application of the estimated average control efficiencies specified above reduces this contribution to 52 percent of the total particulate emissions from commercial/institutional combustion sources. It is interesting to note that internal combustion sources account for 22 and 38 percent of the total commercial/institutional sector CO and HC emissions, respectively, despite the small amount of fuel consumed by these sources (approximately 1 percent of the total commercial fuel). Emissions of all pollutants are relatively minor in comparison to national totals,

TABLE 53. CURRENT NATIONWIDE EMISSIONS OF CRITERIA POLLUTANTS FROM COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES

Combustion source category	Emissions (Gg/year)[a]				
	Particulates	NO_x	SO_2	CO	HC
Gas boilers	4.4	110	0.6	17.6	6.6
Distillate oil boilers	7.2	82	127	9.6	3.6
Residual oil boilers	52	241	649	11	4.2
Bituminous, pulverized dry bottom boilers	68	7	15	0.4	0.1
Bituminous stokers	70	8.2	54	14	4.1
Anthracite stokers	7.2	7.2	16	0.8	0.3
Wood stokers	22	1.0	6.5	10	10
Gas reciprocating engines	0.1	35	nil	7.5	10
Oil reciprocating engines	1.0	36	2.4	10	7.5
Total	232	527	871	81	46

[a] Uncontrolled emissions.

accounting for approximately 1.7 percent, 4.9 percent, 3.0 percent, 0.5 percent and 0.3 percent of emissions of particulate, NO_x, SO_2, CO, and HC, respectively, from all stationary sources in 1978.

Current trace element emissions from uncontrolled commercial/institutional sources are summarized in Table 54. Emissions from gas-fired sources and internal combustion engines are negligible and are not included in the table. Total emissions were estimated from the fuel consumption data shown in Table 52 and the mean emission factors measured in the program. An exception was the use of the existing data base for the vanadium emission factor for residual oil. Further, emissions from the solid fuel fired combustion sources were adjusted as required for the rated control efficiencies. In the case of the bituminous stokers, the mean uncontrolled emission factor values were further adjusted to provide weighted emission factors, based on the capacity distribution of the three types of stokers[8] and their corresponding EPA AP-42 particulate emission factors. This capacity weighted particulate emission factor is 105A, as compared to EPA emission factors of 39A, 98A and 254A for underfeed, overfeed and spreader stokers, respectively.

Trace element emissions of less than 1 metric ton per year are equivalent to the values of < 0.001 Gg/yr shown in Table 54. Because of the limited data base, the accuracy of Level I sampling and analysis procedures, and the variability of the trace element content of fuels, estimating total emissions to values less than 1 metric ton per year did not appear warranted. However, a comparison of the emissions of those trace elements emitting less than one metric ton per year can be made by referring to emission factor data for elements by source categories presented in the previous section.

Trace element emissions from oil-fired sites represent 57 percent of uncontrolled emissions and 72 percent of controlled emissions. About 82 percent of the oil-fired emissions are the result of residual oil combustion. Nationwide emissions of trace elements from wood combustion, extrapolated from the one wood-fired boiler tested, are negligible. However, the particulate emission factor for this unit was only 10 percent of the AP-42 emission factor and the data for wood are low by approximately a factor of 10.

TABLE 54. CURRENT NATIONWIDE EMISSIONS OF TRACE ELEMENTS FROM COMMERCIAL/INSTITUTIONAL EXTERNAL COMBUSTION SOURCES

Element	Emissions (Gg/year)[a]					
	Distillate oil-fired boilers	Residual oil-fired boilers	Bituminous, pulverized dry bottom boilers	Bituminous stokers	Anthracite stokers	Wood stokers
Aluminum (Al)	0.002	0.22	1.2	0.18	1.4	< 0.001
Arsenic (As)	0.002	0.01	0.04	0.001	0.003	< 0.001
Boron (B)	0.002	0.01	0.07	0.002	0.05	< 0.001
Barium (Ba)	0.01	0.01	0.11	0.004	0.01	< 0.001
Beryllium (Be)	< 0.001	< 0.001	0.001	< 0.001	< 0.001	-
Bromine (Br)	0.01	0.001	0.004	< 0.001	0.002	< 0.001
Calcium (Ca)	1.0	1.1	0.68	0.07	0.04	< 0.001
Cadmium (Cd)	0.003	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Cobalt (Co)	0.003	0.03	0.007	< 0.001	0.001	< 0.001
Chromium (Cr)	0.04	0.07	0.09	0.03	0.02	< 0.001
Copper (Cu)	0.25	0.13	0.02	0.002	0.009	< 0.001
Fluorine (F)	0.02	0.12	0.04	0.004	0.01	< 0.001
Iron (Fe)	0.65	0.53	0.83	0.22	0.30	< 0.001
Mercury (Hg)	0.002	0.003	< 0.001	< 0.001	< 0.001	< 0.001
Potassium (K)	0.07	0.30	0.31	0.03	0.14	0.002
Lithium (Li)	0.002	0.001	0.01	< 0.001	0.004	< 0.001
Magnesium (Mg)	0.05	0.16	0.47	0.006	0.03	< 0.001
Manganese (Mn)	0.007	0.07	0.02	0.01	0.002	< 0.001
Molybdenum (Mo)	0.02	0.09	0.04	0.004	0.004	< 0.001
Sodium (Na)	0.12	0.58	0.36	0.01	0.04	< 0.001
Nickel (Ni)	0.13	1.1	0.14	0.01	0.02	< 0.001
Phosphorus (P)	0.007	0.15	0.11	0.04	0.10	0.004
Lead (Pb)	0.06	0.01	0.009	0.001	0.006	< 0.001
Antimony (Sb)	0.002	0.004	0.001	< 0.001	< 0.001	< 0.001
Selenium (Se)	0.003	0.001	0.02	< 0.001	0.002	< 0.001
Silicon (Si)	0.21	2.2	2.7	0.08	1.7	< 0.001
Tin (Sn)	0.002	0.001	0.002	< 0.001	< 0.001	< 0.001
Strontium (Sr)	0.01	0.001	0.07	0.017	< 0.001	< 0.001
Thorium (Th)	-	-	< 0.001	< 0.001	< 0.001	-
Uranium (U)	-	-	0.001	< 0.001	< 0.001	-
Vanadium (V)	0.03	5.1	0.02	< 0.001	< 0.001	< 0.001
Zinc (Zn)	0.03	0.65	0.04	0.001	< 0.001	0.004
Total	2.8	12.7	7.4	0.65	3.9	~ 0.01

[a] Uncontrolled emissions: a values of less than < 0.001 represents emissions of less than 1 metric ton/yr.

Event with this adjustment, trace element emissions from wood-fired combustion sources are well below 1 percent of the total controlled nationwide emissions from commercial/institutional sources.

Among the trace elements, vanadium, primarily from residual oil sources, and aluminum, calcium, iron, potassium, sodium, nickel, and silicon are emitted in the largest quantities. Total controlled and uncontrolled emissions of trace elements listed in Table 54 from commercial/institutional combustion sources were about 21.5 and 27.5 Gg/year in 1978. Controlled emissions of 21.5 Gg/year represent approximately 1.5 percent of trace element emissions from utility sources.

Because of the limited amount of POM data and the high emission levels found at Sites 219 and 220, no attempt has been made here to tabulate nationwide emission estimates of POM compounds from commercial/institutional solid-fuel-fired combustion sources. However, estimates of nationwide emissions of the most prevalent POM compounds emitted from gas- and oil-fired sources are presented in Table 55. Estimates of total POM were also made by adding the contribution of POM compounds not listed in the table. Total POM emissions from the external combustion sources listed in Table 55 are about 55 Mg/year, with oil-fired reciprocating engines contributing an additional 11 Mg/year. The contribution of the internal combustion sources is large relative to the amount of fuel used by reciprocating engines. The total POM emissions from the source categories in Table 55 are a small fraction of total POM emissions from stationary sources and consist of relatively harmless compounds with MATE values in the 1 to 230 mg/m^3 range. However, POM emissions from the solid fuel-fired combustion source categories have not been estimated and could contribute significantly to both the quantity and potential hazard of emissions.

Estimates of criteria pollutant emissions in 1985 based on projected fuel consumption by the commercial/institutional sector are presented in Table 56. A comparison of the data in Tables 53 and 56 indicates a modest 13 percent increase in uncontrolled particulate emissions, corresponding to a 9 percent increase if present levels of controls are applied. The increase in particulate emissions is attributable to the projected increase in coal and wood

TABLE 55. CURRENT NATIONWIDE EMISSIONS OF POM COMPOUNDS FROM COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES

POM compound	Emissions (Mg/year) Gas-fired boilers	Distillate oil-fired boilers	Residual oil-fired boilers	Oil-fired reciprocating engines
Naphthalene	16.5	25	3.5	4.7
Trimethyl propenyl naphthalene	0.8	-	0.2	-
Phenanthrene	0.7	-	0.4	1.5
Pyrene	1.6	-	-	0.06
Biphenyl	-	-	-	0.6
Methyl phenanthrene	-	-	0.2	1.4
Total	24.1	25	5.3	10.8

TABLE 56. ESTIMATED 1985 NATIONWIDE EMISSIONS OF CRITERIA POLLUTANTS FROM COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES

Combustion source category	Emissions (Gg/year)[a] Particulates	NO_x	SO_2	CO	HC
Gas boilers	5.1	128	0.7	21	7.7
Distillate oil boilers	6.6	75	116	8.8	3.3
Residual oil boilers	48	224	603	10	3.9
Bituminous, pulverized dry bottom boilers	82	8.5	18	0.5	0.1
Bituminous stokers	85	10	65	17	5.0
Anthracite stokers	7.2	7.2	16	0.8	0.3
Wood stokers	27	1.2	7.9	12	12
Gas reciprocating engines	0.1	42	nil	9.0	12
Oil reciprocating engines	1.0	36	2.4	10	7.5
Total	262	532	824	89	52
Percent change from 1978	+13%	+1%	-5%	+10%	+13%

[a] Uncontrolled emissions.

consumption. Emissions of SO_2 will decline by about 5 percent because of the increase in the use of natural gas and the decrease in oil consumption. Emissions of NO_x, CO and HC will increase by about 1 percent, 10 percent and 13 percent, respectively.

Trace element emissions from the commercial/institutional sector will increase by about 8 percent to 23.3 Gg/year, assuming the present level of particulate control. POM emissions can also be expected to increase because of the projected increase in solid fuel use by the commercial sector. This increase could be significant if Sites 219 and 220 are representative of only a modest fraction of other wood- and bituminous-fired stokers in the commercial/institutional sector.

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APPENDIX A

CRITERIA FOR EVALUATING THE ADEQUACY OF EXISTING EMISSIONS DATA FOR CONVENTIONAL STATIONARY COMBUSTION SYSTEMS

APPENDIX A

CRITERIA FOR EVALUATING THE ADEQUACY OF EXISTING EMISSIONS DATA FOR CONVENTIONAL STATIONARY COMBUSTION SYSTEMS

A major task in the present program was to identify gaps and inadequacies in the existing emissions data base for conventional stationary combustion systems. The output from this effort will be used in the planning and performance of a combined field and laboratory program as required to complete adequate emissions assessment for each of the combustion source types.

The criteria for assessing the adequacy of emissions data are developed by considering both the reliability and variability of the data. The general approach is to use a three-step process as described below. This approach is applicable to the evaluation of the existing emissions data as well as emissions data collected during the course of this program.

STEP 1

In the first step of the evaluation process, the emissions data are screened for adequate definition of process and fuel parameters that may affect emissions as well as validity and accuracy of sampling and analysis method. The screening mechanism is devised to reject emissions data that would be of little or no use. Acceptance of emissions data in this screening step only indicates the possibility for further analysis and in no way suggests that these data are valid or reliable. As such, the data screening criteria are often expressed in terms of minimum requirements. These screening criteria are depicted in Figure A-1 and discussed in detail below.

The first criterion that will be applied is that only source test data will be accepted. A significant portion of the data base, and especially those contained in the National Emissions Data Systems (NEDS), were developed by the use of standard emission factors* and not derived from actual test data. The inclusion of these estimated emissions data in the data base would lead to the obviously biased conclusion that the actual emissions were the same as those predicted by the standard emission factors.

The second criterion that will be applied is an adequate description of the source. To further analyze the emissions data, there must be sufficient information to designate the combustion source according to the

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*Mostly by the use of emission factors published in the EPA Publication AP-42: Reference A-1.

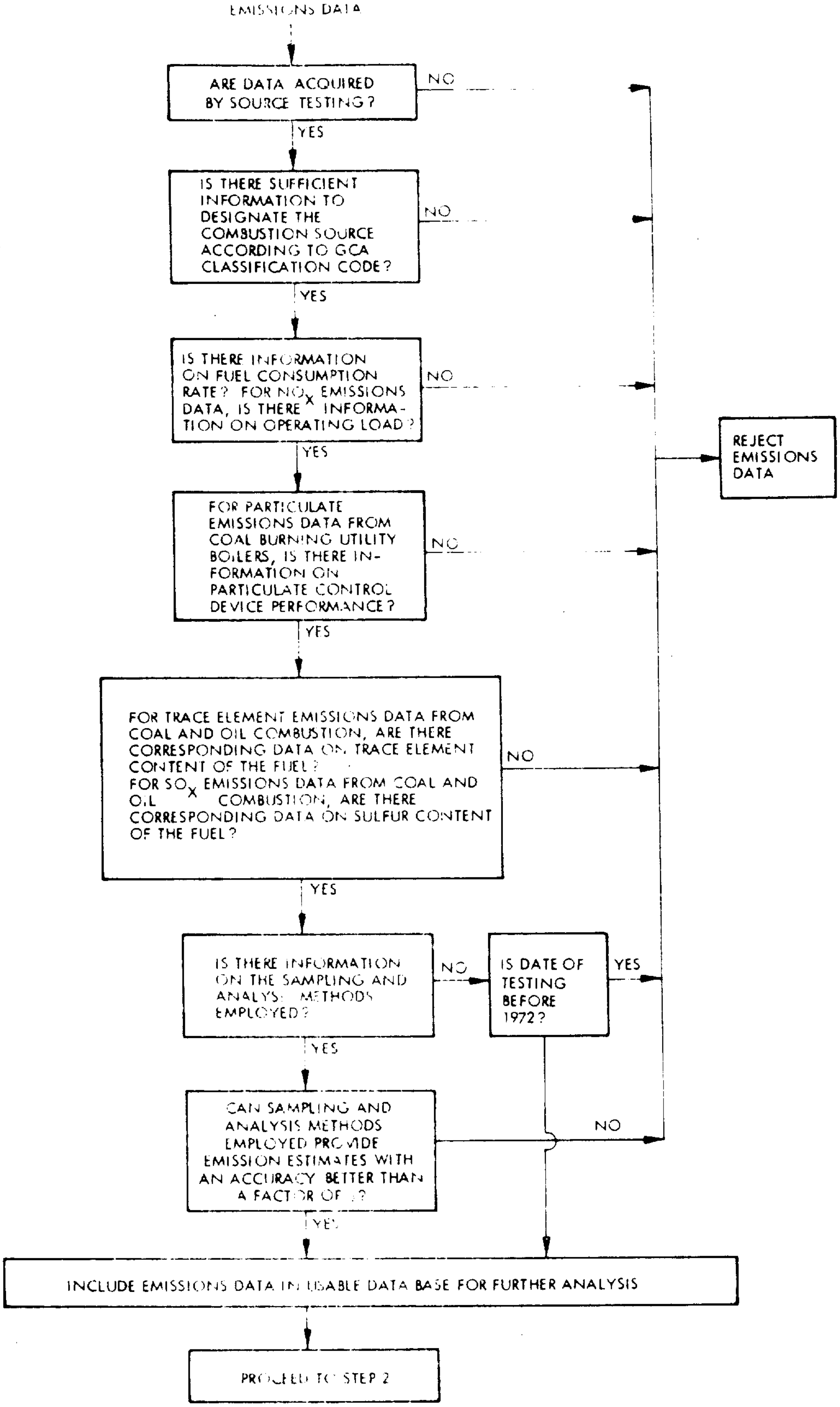

Figure A-1. Step 1 Screening Mechanism for Emissions Data appropriate GCA classification code. As a minimum, the information provided should include: the function of the combustion source (electricity generation, industrial, commercial/institutional, or residential), the type of combustion (external combustion or internal combustion), the type of fuel used (coal, oil, gas, or refuse), and in the case of coal combustion, the type of furnace (pulverized dry bottom, pulverized wet bottom, cyclone, or stoker). For emissions data that are judged to be valuable* and otherwise acceptable, efforts will be made to acquire the needed source description information directly from the investigator or the plant operator.

The third criterion for acceptance of emissions data for further analysis in an adequate definition of the combustion system operating mode. For example, operating load has a large effect on NO_x emissions from combustion systems. It is therefore important to have an adequate definition of the test conditions that may affect emissions. As a minimum, there must be information on the fuel consumption rate for the emissions data to be accepted. The fuel consumption rate is necessary for the calculation of emission factors. For NO_x emissions data, field and test results that do not include information on operating load will be considered unacceptable because they cannot be used to estimate emissions from a typical combustion system nor could they be used to estimate emissions at any specific load. For other types of emission data, the operating load information will be considered a useful parameter for data correlation but not an absolute requirement for data acceptance.

The fourth criterion for accpetance of emissions data for further analysis is an adequate definition of the pollution control device performance. Control device performance will affect not only total emissions but will influence, for example, the particle size distribution and composition of flue gas emissions. The application of design efficiencies must be approached with caution in estimating uncontrolled emissions. If a design efficiency of 99 percent is used and if the control device operating efficiency is only 90 percent, the calculated uncontrolled emissions would be 10 times larger than the actual case. Because coal burning utility boilers are equipped with particulate control devices, particulate emissions data from the coal burning utility sector will not be considered acceptable unless accompanied by the particulate control device performance data. The application of particulate control devices is less frequent for the industrial, commercial/institutional and residential sectors, and also much less frequent for the oil burning utility sector and nonexistent for the gas burning utility sector. For these combustion source types, emissions data will be accepted as uncontrolled emissions data, unless there is information implying the contrary. As noted in the foregoing discussions acceptance of emissions data at this screening step does not suggest that the data are necessarily valid or reliable. In the second step of the data evaluation process, methods for rejecting outlying data points will be defined. Controlled emissions data that have been mistakenly assumed to be uncontrolled emissions data because of a lack of information will be identified as outlying data points and be rejected in this second step.

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*In this context, emissions data for trace elements, POM, PCB, and organics are considered to be more valuable because of the paucity of data.

The fifth criterion that will be used to judge the usefulness of the emissions data is the availability of the fuel analysis data. This is especially true for emissions of trace elements and SO_x. The trace element content of coal can vary by one to two orders of magnitude, and emissions are closely related to the trace element content of the coal. No trace elements are present in appreciable amounts in gaseous hydrocarbons; however, nickel, vanadium and sodium are present in appreciable amounts in some fuel oil. To estimate trace element emission levels from all sources within a given category, the fraction of each trace element exiting the system in each effluent stream must be estimated. Thus, trace element emissions data from coal and oil combustion that are not accompanied by analysis data on the trace element content of the fuel will not be accepted. Similarly, SO_x emissions are directly related to the sulfur content of the fuel. SO_x emissions data from coal and oil combustion that do not include information on the sulfur content of the fuel will therefore not be accepted.

The last criterion that will be applied is an evaluation of the accuracy of the sampling and analysis methods used. To determine emissions from a given site to within a factor of 3, both the sampling and analysis procedures used must be capable of providing an accuracy that is better than a factor of 3. The list of methods available for the sampling and analysis of general stream types and chemical classes and species is very extensive, and has been described in detail in two recent TRW reports (References A-2 and A-3). In general, most of the sampling and analysis procedures recommended in these two references are adaptations of standard EPA, ASTM, API methods, and have an accuracy and/or precision of ± 10 to 20 percent or better. Emissions data obtained by these recommended methods or techniques will be considered acceptable. Emissions data obtained by methods or techniques not listed in these two references will be subjected to careful review and rejected if it is determined that the sampling or analysis method used would not be able to provide emission estimates within an accuracy factor of 3 or better. Special emphasis will be placed on the review of sampling and analysis methods used for obtaining PCB, POM, particulate sulfate, and trace elements emissions data. In cases where information on the sampling and analysis methods used is unavailable, the date of testing will be used as the criterion for inclusion or rejection of the emissions data in the usable data base. Emissions data obtained before 1972 will be generally considered unacceptable because of probable use of unreliable sampling or analysis procedures. The 1972 cut-off date is selected on the basis that the EPA Method 5 (40-CFR-60, Appendix C, Methods), which has been more or less recognized nationally as the standard method for sampling particulates, was introduced in late 1971. Furthermore, most of the more sophisticated sampling and analysis techniques for obtaining emissions data, and especially those for measuring pollutants for which data are lacking (such as trace elements and particulate sulfate), were not introduced and used before 1972.

STEP 2

In the second step of the data evaluation process, emissions data that have been identified as usable in the screening step will be subjected for further engineering and statistical analysis to determine the internal consistency of the test results and the variability in emissions factors.

Emissions data included in the usable data base will first be categorized according to the 5-column GCA combustion system classification code and the unit operation from which the pollutants are emitted. For NO_X, the emissions data will be further categorized according to the method of NO_X control; no control, staged firing, low excess air, reduced load, or flue gas recirculation. Emissions factors for individual sites, normally expressed in the form of lb/MM Btu or lb/ton, will then be calculated for each pollutant/unit operating pair. In the case of trace element stack emissions from coal and oil combustion, these emission factors will be calculated in the form of the fraction of each trace element emitted to the atmosphere.

The emission factors calculated for each pollutant/unit operation pair will be evaluated in terms of consistency of test results among sites. All the data subjected to detailed scrutiny and discarded unless there is additional information to reclassify the data into the correct category. The decision on whether an outlier is a reasonable result or whether it may be discarded as being an improbable member of the group will be based on the method of Dixon. The method of Dixon is a statistical technique applicable to the rejection of a single outlying point from a small group of data and is described in detail in Attachment A.

The variability of the emission factors will next be calculated. The variability is defined as

$$V = \frac{t\ s(\bar{x})}{(\bar{x})} \qquad (1)$$

where $\bar{x}$ is the estimated mean value of the emission factor, $s(\bar{x})$is the estimated standard deviation of the mean, and t is a multiple of the estimated standard deviation of the mean value $s(\bar{x})$. The value of t depends on the degree of freedom and the confidence level of the interval containing the true mean μ, and is given in standard statistics texts. For the present program, t values at 95 percent confidence level will be used in calculating the variability of emission factors.

The main thrusts in this second step are: (1) to determine the emission factors for each pollutant/unit operation pair and for each combustion source category; (2) to discard outlying data points using the method of Dixon; and (3) to calculate the percent variability of the emission factors. The values calculated in this step will be used in Step 3.

STEP 3

The final step in the data evaluation process involves a method developed by the Monsanto Research Corporation (MRC) for the evaluation of data adequacy. This quantitative method will indicate where additional emissions data are needed. The method is based on both the potential environmental risks associated with the emission of each pollutant and the quality of the existing emissions data.

The potential environmental risks associated with pollutant emissions are determined by the use of source severity factors S. For emissions to the atmosphere, the source severity S is defined as the ratio of the calculated maximum ground level concentrations of the pollutant species to the level at which a potential environmental hazard exists. The simple Gaussian Plume equation for ground level receptors at the plume centerline is the dispersion model used for determining the ground level concentration. The potential environmental hazard level is taken to be the Threshold Limit Value (TLV) divided by 300 for noncriteria pollutants and the ambient air quality standard for the criteria pollutants. The mean source severity S for noncriteria pollutants is calculated as follows:

$$S = \frac{5.5\ Q}{(TLV)h^2} \qquad (2)$$

where Q = emission rate, g/s

TLV = threshold limit value, g/m^3

h = stack height, m

For the five criteria pollutants, the equations for calculating mean source severity S is given in the following table:

Pollutant	Severity equation	
Particulate	$S = 70Qh^{-2}$	(3)
SO_X	$S = 50Qh^{-2}$	(4)
NO_X	$S = 315Qh^{-2.1}$	(5)
Hydrocarbons	$S = 162.5Qh^{-2}$	(6)
CO	$S = 0.78Qh^{-2}$	(7)

The emission rate is calculated by the following equation:

$$Q = \frac{TC}{TNP}\ (EF)\ (GPP)\ (YPS) \qquad (8)$$

where TC = total fuel consumption, tons/year

TNP = total number of plants/sites

EF = emission factor, lb/ton

GPP = 453.6 g/lb

YPS = 3.1688×10^{-8} yr/s

For discharges to the water, the source severity factor S is calculated as follows:

$$S = \frac{V_D\ C_D + f_1 f_2}{V_R D} \qquad (9)$$

where V_D = discharge flow rate, m^3/s

C_D = discharge concentration, g/m^3

S_G = leachable solid waste generation, g/sec

f_1 = fraction of the solid waste to water

f_2 = fraction of the material in the solid waste

V_R = river flow rate, m^3/s

D = drinking water standard, g/m^3

The mean source severity factor S for each pollutant/unit operation pair will be used in the evaluation of data adequacy. The method for evaluating data adequacy is outlined below.

Case 1: When Emissions Data Are Available and Usable

1. Determine the mean emission factor $\bar{x}$ and the variability of the emission factor $ts(\bar{x})/\bar{x}$ for each pollutant/unit operation pair. (This will be done in Step 2 of the data evaluation process.)

2. Determine the mean severity factor S for each pollutant/unit operation pair by using the mean emission factor $\bar{x}$.

3. If the variability in emission factor < 70 percent, additional data are not needed.

4. If the variability in emission factor > 70 percent and S > 0.05, the current data base is judged to be inadequate and there is need for additional data.

5. If the variability in emission factor > 70 percent and $S \leq 0.05$, determine the severity factor S_u by using the emission factor $\bar{x}_u$:

   $$\bar{x}_u = \bar{x} + ts(x)$$

   S_u is the upper bound for the severity factor S. The current data base is judged to be adequate if $S_u \leq 0.05$ and inadequate if $S_u > 0.05$.

Case 2: When Emissions Data Are Not Available

1. Determine, if possible, from fuel analysis, mass balance and physico-chemical considerations the upper bound $\bar{x}_u$ of the emission factor $\bar{x}$. For trace element stack emissions, for example, $\bar{x}_u$ can be determined by assuming that all the trace elements present in the fuel are emitted through the stack.

2. Determine the upper bound S_u of the severity factor S for each pollutant/unit operation pair by using the emission factor $\bar{x}_u$.

3. The current data base is judged to be adequate if $S_u \leq 0.05$ and inadequate if $S_u > 0.05$.

As discussed in a recent Monsanto report (Reference A-4), an allowable uncertainty in emission factor of ± 70 percent (factor of 3) would lead to an uncertainty of less than 10 in S_{calc}, which has been defined as the acceptable uncertainty factor for S.

As a result of the application of the above data evaluation criteria, pollutant/unit operation pairs that have been inadequately characterized will be identified to permit the planning of field tests for acquisition of additional emissions data.

ATTACHMENT A

METHOD OF DIXON FOR DISCARDING OUTLYING DATA*

The method of Dixon provides a test for extreme values using range. If the observations in the sample are ranked, the individual values can be identified x_1, x_2, x_3, . . ., x_{n-1}, x_n. It is immaterial whether the ranking proceeds from high values to low or from low values to high. The Dixon extreme-value test gives the maximum ratio of differences between extreme-ranking observations to be expected at various probability levels and for different sample sizes. Table A-1 gives the test ratios and maximum expected values. For samples less than about eight observations, the ratio of the difference between the extreme and the next-to-extreme value to the total range is compared with the tabulated values for the same sample size. If the observed ratio exceeds the tabulated maximum expected ratio, the extreme value may be rejected with the risk of error set by the probability level. For samples between about 9 and 14, the ratio of the difference between the first and third ranking observations to the difference between the first and next to last is tested. For samples of 15 or more, the ratio of the difference between the first and the third ranking observations to the difference between the first- and the second-from last observation is used.

In the evaluation of the emissions data, the 0.05 probability level will be used as the basis for discarding outlying data.

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*Volk, W. Applied Statistics for Engineers. New York McGraw-Hill, Inc. 2nd ed. p. 387-388. 1969.

TABLE A-1. MAXIMUM RATIO OF EXTREME RANKING OBSERVATIONS

Recommended for sample size	Rank difference ratio	Sample size, n	Maximum ratio		
			Probability level		
			0.10	0.05	0.01
$n < 8$	$\frac{x_2 - x_1}{x_n - x_1}$	3	0.886	0.941	0.988
		4	0.679	0.765	0.889
		5	0.557	0.642	0.780
		6	0.482	0.560	0.698
		7	0.434	0.507	0.637
$8 < n < 15$	$\frac{x_3 - x_1}{x_{n-1} - x_1}$	8	0.650	0.710	0.829
		9	0.594	0.657	0.776
		10	0.551	0.612	0.726
		11	0.517	0.576	0.679
		12	0.490	0.546	0.642
		13	0.467	0.521	0.615
		14	0.448	0.501	0.593
$n \geq 15$	$\frac{x_3 - x_1}{x_{n-2} - x_1}$	15	0.472	0.525	0.616
		16	0.454	0.507	0.595
		17	0.438	0.490	0.577
		18	0.424	0.475	0.561
		19	0.412	0.462	0.547
		20	0.401	0.450	0.535

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APPENDIX B

DATA REDUCTION PROCEDURE

APPENDIX B

DATA REDUCTION PROCEDURE

Stack emissions data reported from field measurements or laboratory analyses are often expressed in terms of volume concentration (ppmv) or mass concentration (mg/m³, μg/m³). To convert these emissions data to the emission factor form, the following data reduction procedure, adopted from Reference B-1, is used.

The number of gm moles of flue gas per gm of fuel can be computed using the fuel composition analysis and effluent O_2 concentration:

$$n_{FG} = \frac{4.762\ (n_C + n_S) + 0.9405\ n_H - 1.881\ n_O}{1-4.762\ (O_2/100)} = \frac{F}{1-4.762\ (O_2/100)}$$

where: n_{FG} = gm moles of dry effluent/gm of fuel under actual operating conditions

n_j = gm moles of element j in fuel per gm of fuel

O_2 = volumetric O_2 concentration in percent

F = gm moles of dry effluent/gm of fuel under stoichiometric combustion

The average values of F for natural gas and various liquid fuels are given in Table B-1. The value of F for coal must be computed on an individual basis because of the variation in the elemental composition of different coals.

For emission species measured on a volumetric concentration basis (ppmv), the emission factor expressed as ng/J can be computed using the following equation:

$$\begin{Bmatrix}\text{Emission}\\ \text{Factor}\end{Bmatrix} (\text{ng/J}) = \frac{\begin{Bmatrix}\text{Volumetric}\\ \text{Concentration}\end{Bmatrix}_s (\text{ppmv}) \times F \times M_s}{\begin{Bmatrix}\text{Fuel}\\ \text{Heating Value}\end{Bmatrix} (\text{kJ/kg fuel})} \times \frac{1000}{1-4.762\ (O_2/100)}$$

where s = subject emission species

M_s = molecular weight of species s

TABLE B-1. ELEMENTAL COMPOSITION AND HIGHER HEATING VALUE OF FUELS*

Fuel	Natural gas	No. 2 distillate oil	Kerosene	Residual oil
n_C	0.06221	0.06994	0.06994	0.07160
n_S	0	0.00006	0	0.00031
n_H	0.23116	0.13889	0.15873	0.10913
n_O	0.00040	0.001125	0	0.00125
F	0.51215	0.45983	0.48234	0.44037
Heating Value	53,310 kJ/kg	45,040 kJ/kg	47,710 kJ/kg	43,760 kJ/kg

*The composition and heating value data are obtained from Reference B-2.

For emission species measured on a mass concentration basis (mg/m^3 or $\mu g/m^3$) at 20°C, the emission factor expressed as ng/J, can be computed using the following equation:

$$\begin{Bmatrix}\text{Emission}\\ \text{Factor}\end{Bmatrix} (ng/J) = \frac{\begin{Bmatrix}\text{Mass}\\ \text{Concentration}\end{Bmatrix}_S (\mu g/m^3) \times F \times 24.04}{\begin{Bmatrix}\text{Fuel}\\ \text{Heating Value}\end{Bmatrix} (kJ/kg\ fuel)} \times \frac{1}{1-4.762\ (O_2/100)}$$

The higher heating values of natural gas and various liquid fuels are also given in Table B-1.

Note that the data reduction procedure described here significantly minimizes errors introduced in data reduction by eliminating terms that are subject to large measurement errors, such as stack velocity and temperature measurements. The only stack parameter needed in data reduction is the volumetric O_2 concentration, which can usually be determined by gas chromatography with great accuracy.

Example Calculation--

The NO_X emission from a gas fueled gas turbine is reported to be 200 ppmv at an O_2 effluent concentration of 15 percent. Calculate the emission factor for NO_X (as NO_2) in ng/J.

Emission factor for NO_X (as NO_2)

$$= \frac{200 \times 0.51215 \times 46.0}{53310} \times \frac{1000}{1-4.762 \times 0.15}\ ng/J$$

$$= 309\ ng/J$$

REFERENCES

B-1. Coppersmith, F. M., R. F. Jastrzebski, D V. Giovanni and S. Hersh. Con Edison's Gas Turbine Test Program: A Comprehensive Evaluation of Stationary Gas Turbine Emission Levels. Paper presented at the 67th Annual Meeting of the Air Pollution Control Association, Denver, Colorado, June 9-13, 1974.

B-2. Steam/Its Generation and Use. Revised 38th Edition. The Babcock and Wilcox Company, New York, New York. 1975.

APPENDIX C

SSMS DATA FOR COMMERCIAL/INSTITUTIONAL COMBUSTION SOURCES

OIL-FIRED SOURCES

SITE 120: RESIDUAL OIL-FIRED SOURCE

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0002	< 0.041	< 0.44	< 0.48	< 0.015	< 0.40	< 0.029
TH	< 0.0003	< 0.059	< 0.63	< 0.69	< 0.022	< 0.58	< 0.042
BI	< 0.0001	< 0.018	< 0.20	< 0.21	< 0.0068	< 0.18	< 0.013
PB	0.028	< 0.075	< 0.41	0.028 TO 0.48	0.0009 TO 0.015	< 0.37	< 0.027
TL	< 0.0001	< 0.023	< 0.24	< 0.27	< 0.0085	< 0.23	< 0.016
HG	< 0.0003	< 0.053	< 0.56	< 0.62	< 0.020	< 0.26	< 0.0001
AU	< 0.0002	< 0.030	< 0.33	< 0.36	< 0.011	< 0.30	< 0.022
PT	< 0.0005	< 0.089	< 0.95	< 1.0	< 0.033	< 0.44	< 0.0001
IR	< 0.0002	< 0.047	< 0.50	< 0.55	< 0.017	< 0.46	< 0.033
OS	< 0.0003	< 0.051	< 0.55	< 0.60	< 0.019	< 0.50	< 0.036
RE	< 0.0002	< 0.032	< 0.35	< 0.38	< 0.012	< 0.32	< 0.023
W	< 0.0006	< 0.043	< 0.46	< 0.51	< 0.016	< 0.84	< 0.060
TA	< 0.0001	< 0.019	< 0.21	< 0.23	< 0.0072	< 0.095	< 0.0001
HF	< 0.0003	< 0.054	< 0.58	< 0.63	< 0.020	< 0.53	< 0.038
LU	< 0.0001	< 0.013	< 0.14	< 0.15	< 0.0047	< 0.12	< 0.0089
YB	< 0.0001	< 0.018	< 0.20	< 0.22	< 0.0068	< 0.18	< 0.013
TM	< 0.0001	< 0.011	< 0.12	< 0.13	< 0.0042	< 0.11	< 0.0079
ER	< 0.0002	< 0.033	< 0.35	< 0.39	< 0.012	< 0.33	< 0.023
HO	< 0.0001	< 0.011	< 0.12	< 0.13	< 0.0040	< 0.11	< 0.0077
DY	< 0.0005	< 0.019	< 0.20	< 0.22	< 0.0070	< 0.19	< 0.013
TB	< 0.0001	< 0.0051	< 0.055	< 0.060	< 0.0019	< 0.051	< 0.0036
GD	< 0.0002	< 0.019	< 0.20	< 0.22	< 0.0070	< 0.19	< 0.013
EU	< 0.0001	< 0.0085	< 0.091	< 0.100	< 0.0032	< 0.084	< 0.0060
SM	< 0.0009	< 0.033	< 0.35	< 0.38	< 0.012	< 0.32	< 0.023
ND	0.0019	< 0.041	< 0.44	0.0019 TO 0.48	< 0.0001 TO 0.015	< 0.40	< 0.029
PR	0.0004	< 0.0072	< 0.078	0.0004 TO 0.085	< 0.0001 TO 0.0027	< 0.072	< 0.0051
CE	0.0012	< 0.0098	< 0.100	0.0012 TO 0.11	< 0.0001 TO 0.0036	< 0.096	< 0.0069
LA	0.0018	< 0.011	< 0.11	0.0018 TO 0.12	< 0.0001 TO 0.0039	< 0.100	< 0.0075
BA	0.074	0.020	< 0.16	0.094	0.0030	0.20	0.014
CS	< 0.0001	< 0.0017	< 0.018	< 0.0001 TO 0.020	< 0.0001 TO 0.0006	< 0.017	< 0.0012
I	< 0.0004	0.028	< 0.30	0.028 TO 0.30	0.0009 TO 0.0096	< 0.28	< 0.020
TE	< 0.0001	< 0.024	< 0.25	< 0.28	< 0.0088	< 0.23	< 0.017
SB	0.0002	< 0.016	< 0.18	0.0002 TO 0.19	< 0.0001 TO 0.0061	< 0.16	< 0.012
SN	< 0.0019	< 0.023	< 0.25	< 0.27	< 0.0087	< 0.23	< 0.016
CD	0.0004	< 0.029	< 0.31	0.0004 TO 0.34	< 0.0001 TO 0.011	< 0.29	< 0.021
AG	< 0.0001	< 0.0085	< 0.091	< 0.099	< 0.0032	< 0.042	< 0.0001
PD	< 0.0001	< 0.024	< 0.25	< 0.28	< 0.0088	< 0.23	< 0.017
RH	< 0.0001	< 0.0082	< 0.088	< 0.096	< 0.0031	< 0.081	< 0.0058

SITE 120: RESIDUAL OIL-FIRED SOURCE

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0002	< 0.030	< 0.32	< 0.35	< 0.011	< 0.30	< 0.021
MO	0.0060	< 0.028	< 0.30	0.0060 TO 0.33	0.0002 TO 0.0100	< 0.55	< 0.039
NB	< 0.0001	< 0.0035	< 0.038	< 0.0001 TO 0.041	< 0.0001 TO 0.0013	0.034	0.0025
ZR	0.0022	< 0.013	< 0.14	0.0022 TO 0.15	< 0.0001 TO 0.0049	< 0.13	< 0.0093
Y	0.0009	< 0.0054	< 0.058	0.0009 TO 0.064	< 0.0001 TO 0.0020	< 0.054	< 0.0038
SR	0.024	< 0.038	< 0.073	0.024 TO 0.11	0.0008 TO 0.0035	0.066	0.0047
RB	0.0014	< 0.0033	< 0.018	0.0014 TO 0.021	< 0.0001 TO 0.0007	< 0.016	< 0.0012
BR	< 0.0024	0.041	< 0.43	0.041 TO 0.43	0.0013 TO 0.014	< 0.40	< 0.028
SE	0.0089	< 0.032	< 0.17	0.0089 TO 0.20	0.0003 TO 0.0065	< 2.6	< 0.19
AB	0.032	< 0.0063	< 0.068	0.032 TO 0.074	0.0010 TO 0.0023	0.087	0.0062
GE	< 0.0015	< 0.011	< 0.12	< 0.13	< 0.0042	< 0.11	< 0.0080
GA	0.023	< 0.0046	< 0.049	0.023 TO 0.054	0.0007 TO 0.0017	0.045	0.0032
ZN	0.066	< 0.39	0.46	0.53	0.017	0.58	0.042
CU	0.040	< 0.26	0.33	0.37	0.012	1.2	0.083
NI	4.6	< 0.45	1.7	6.3	0.20	16.	1.1
CO	0.27	< 0.013	0.064	0.34	0.011	0.50	0.036
FE	5.1	< 0.43	9.1	14.	0.45	120.	8.3
MN	0.023	< 0.022	0.46	0.48	0.015	0.98	0.070
CR	0.013	< 0.065	0.49	0.51	0.016	0.32	0.023
V	0.72	< 0.045	0.046	0.76	0.024	6.6	0.47
TI	0.013	< 0.037	0.092	0.11	0.0033	< 0.52	< 0.037
SC	< 0.0001	< 0.0016	< 0.017	< 0.019	< 0.0006	< 0.0079	< 0.0001
CA	1.1	< 2.7	2.7	3.8	0.12	< 3.6	< 0.26
K	0.33	< 1.0	7.6	7.9	0.25	27.	2.0
CL	< 0.0001	< 0.0100	< 0.11	< 0.12	< 0.0039	< 0.100	< 0.0073
S	160.	<130.	<750.	160. TO 890.	5.1 TO 28.	0.52 (%)	370.
P	0.051	< 3.6	1.2	1.3 TO 3.6	0.041 TO 0.11	1.9	0.14
SI	1.1	< 1.5	20.	22.	0.68	7.2	0.51
AL	0.18	< 0.55	0.98	1.2	0.037	1.1	0.079
MG	0.81	< 1.2	0.90	1.7	0.054	3.1	0.22
NA	< 0.16	< 5.5	4.9	4.9	0.16	150.	11.
F	< 0.0001	< 0.0099	< 0.11	< 0.12	< 0.0037	< 0.098	< 0.0070
O	< 0.0001	< 0.0007	< 0.0076	< 0.0083	< 0.0003	< 0.0012	< 0.0001
N	< 0.0001	< 0.0007	< 0.0076	< 0.0083	< 0.0003	< 0.0010	< 0.0001
C	< 0.0001	< 0.0007	< 0.0076	< 0.0083	< 0.0003	< 0.0010	< 0.0001

SITE 124: RESIDUAL OIL-FIRED SOURCE

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0004	< 0.16	< 0.66	< 0.82	< 0.028	< 0.40	< 0.025
TH	< 0.0005	< 0.23	< 0.95	< 1.2	< 0.041	< 0.58	< 0.037
BI	< 0.0002	< 0.073	< 0.30	< 0.37	< 0.013	< 0.18	< 0.011
PB	< 0.0004	< 0.15	< 3.4	< 3.6	< 0.12	< 0.37	< 0.024
TL	< 0.0002	< 0.091	< 0.37	< 0.46	< 0.016	< 0.23	< 0.014
HG	< 0.0005	< 0.21	< 0.85	< 1.1	< 0.037	< 0.26	< 0.0001
AU	< 0.0003	< 0.12	< 0.49	< 0.61	< 0.021	< 0.30	< 0.019
PT	< 0.0008	< 0.35	< 1.4	< 1.8	< 0.062	< 0.44	< 0.0001
IR	< 0.0004	< 0.19	< 0.76	< 0.94	< 0.033	< 0.46	< 0.029
OS	< 0.0005	< 0.20	< 0.82	< 1.0	< 0.035	< 0.50	< 0.032
RE	< 0.0003	< 0.13	< 0.52	< 0.65	< 0.022	< 0.32	< 0.020
W	< 0.0004	< 0.34	<140.	<140.	< 4.8	< 0.84	< 0.053
TA	< 0.0002	< 0.077	< 0.31	< 0.39	< 0.013	< 0.095	< 0.0001
HF	< 0.0005	< 0.21	< 0.87	< 1.1	< 0.037	< 0.53	< 0.034
LU	< 0.0001	< 0.050	< 0.20	< 0.25	< 0.0088	< 0.12	< 0.0078
YB	< 0.0002	< 0.073	< 0.30	< 0.37	< 0.013	< 0.18	< 0.011
TM	< 0.0001	< 0.045	< 0.18	< 0.23	< 0.0078	< 0.11	< 0.0070
ER	< 0.0003	< 0.13	< 0.53	< 0.66	< 0.023	< 0.33	< 0.021
HO	< 0.0001	< 0.043	< 0.17	< 0.22	< 0.0075	< 0.11	< 0.0067
DY	< 0.0002	< 0.075	< 0.30	< 0.38	< 0.013	< 0.19	< 0.012
TB	< 0.0001	< 0.020	< 0.083	< 0.100	< 0.0036	< 0.051	< 0.0032
GD	< 0.0002	< 0.075	< 0.30	< 0.38	< 0.013	< 0.19	< 0.012
EU	< 0.0001	< 0.034	< 0.14	< 0.17	< 0.0059	< 0.084	< 0.0053
SM	< 0.0003	< 0.13	< 0.53	< 0.66	< 0.023	< 0.32	< 0.020
ND	0.0012	< 0.16	< 0.66	0.0012 TO 0.82	< 0.0001 TO 0.028	< 0.40	< 0.025
PR	0.0002	< 0.029	< 0.12	0.0002 TO 0.15	< 0.0001 TO 0.0050	< 0.072	< 0.0045
CE	0.0011	< 0.039	< 0.16	0.0011 TO 0.20	< 0.0001 TO 0.0068	< 0.096	< 0.0061
LA	0.0023	< 0.042	< 0.17	0.0023 TO 0.21	< 0.0001 TO 0.0074	< 0.100	< 0.0066
BA	0.047	0.16	< 0.23	0.21	0.0072	0.20	0.013
CS	< 0.0001	< 0.0068	< 0.027	< 0.0001 TO 0.034	< 0.0001 TO 0.0012	< 0.017	< 0.0011
I	< 0.0003	< 0.11	< 0.45	< 0.57	< 0.020	< 0.28	< 0.017
TE	< 0.0002	< 0.094	< 0.38	< 0.48	< 0.016	< 0.23	< 0.015
SB	0.0004	< 0.065	< 0.27	0.0004 TO 0.33	< 0.0001 TO 0.011	< 0.16	< 0.0100
SN	0.0011	< 0.093	1.4	1.4	0.049	< 0.23	< 0.014
CD	< 0.0005	< 0.12	< 0.47	< 0.59	< 0.020	< 0.29	< 0.018
AG	< 0.0001	< 0.034	< 0.14	< 0.17	< 0.0059	< 0.042	< 0.0061
PD	< 0.0002	< 0.094	< 0.38	< 0.47	< 0.016	< 0.25	< 0.015
RH	< 0.0001	< 0.033	< 0.13	< 0.17	< 0.0057	< 0.081	< 0.0051

SITE 124: RESIDUAL OIL-FIRED SOURCE

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0003	< 0.12	< 0.49	< 0.61	< 0.021	< 0.30	< 0.019
MO	0.0044	< 0.11	5.3	5.3	0.18	< 0.55	< 0.034
NB	< 0.0001	< 0.014	1.3	1.3	0.046	0.034	0.0022
ZR	0.0017	< 0.053	< 0.21	0.0017 TO 0.27	< 0.0001 TO 0.0092	< 0.13	< 0.0082
Y	0.0006	< 0.022	< 0.088	0.0006 TO 0.11	< 0.0001 TO 0.0038	< 0.054	< 0.0034
SR	0.022	< 0.15	< 0.61	0.022 TO 0.76	0.0008 TO 0.026	0.066	0.0042
RB	0.0006	< 0.0066	< 0.027	0.0006 TO 0.033	< 0.0001 TO 0.0011	< 0.016	< 0.0010
BR	< 0.0015	< 0.16	< 0.65	< 0.81	< 0.028	< 0.40	< 0.025
SE	< 0.0018	< 0.064	< 0.26	< 0.33	< 0.011	< 2.6	< 0.16
AS	0.015	< 0.025	0.29	0.30	0.0100	0.087	0.0055
GE	0.0009	< 0.045	< 0.18	0.0009 TO 0.23	< 0.0001 TO 0.0079	< 0.11	< 0.0070
GA	0.022	< 0.018	< 0.074	0.022 TO 0.093	0.0007 TO 0.0032	0.045	0.0028
ZN	0.11	< 0.73	1.7	1.8	0.062	0.58	0.037
CU	0.025	< 0.52	6.9	7.0	0.24	1.2	0.073
NI	2.8	< 3.6	14.	17.	0.57	16.	1.0
CO	0.27	< 0.100	0.60	0.87	0.030	0.50	0.031
FE	3.0	< 5.1	690.	690.	24.	120.	7.3
MN	0.025	< 0.25	11.	11.	0.37	0.98	0.062
CR	0.0066	< 0.57	24.	24.	0.84	0.32	0.020
V	2.6	< 0.26	0.074	2.7	0.092	6.6	0.42
TI	0.031	< 0.21	< 1.5	0.031 TO 1.7	0.0011 TO 0.057	< 0.52	< 0.033
SC	< 0.0001	< 0.0065	< 0.026	< 0.032	< 0.0011	< 0.0079	< 0.0001
CA	0.98	< 2.0	4.1	5.1	0.17	< 3.6	< 0.22
K	0.074	< 1.6	3.0	3.1	0.11	27.	1.7
CL	< 0.0001	< 0.041	< 0.17	< 0.21	< 0.0072	< 0.100	< 0.0064
S	90.	<110.	**	90. TO ****	3.1 TO 88.	0.52 (%)	330.
P	0.17	< 5.1	21.	21.	0.72	1.9	0.12
SI	3.7	< 8.2	250.	250.	8.8	7.2	0.45
AL	0.38	< 0.77	6.2	6.6	0.23	1.1	0.070
MG	1.5	< 2.8	2.0	3.5	0.12	3.1	0.19
NA	< 0.29	< 7.1	24.	24.	0.83	150.	9.3
F	< 0.0001	< 0.039	< 0.16	< 0.20	< 0.0069	< 0.098	< 0.0061
O	< 0.0001	< 0.0010	< 0.0081	< 0.0092	< 0.0003	< 0.0012	< 0.0001
N	< 0.0001	< 0.0008	< 0.0081	< 0.0090	< 0.0003	< 0.0010	< 0.0001
C	< 0.0001	< 0.0007	< 0.0081	< 0.0089	< 0.0003	< 0.0010	< 0.0001
B	< 0.0033	< 0.042	0.71	0.71	0.025	< 0.100	< 0.0066
BE	0.0004	< 0.0018	0.0037	0.0041	0.0001	0.038	0.0024
LI	0.0051	< 0.021	0.0098	0.015	0.0005	0.031	0.0020

SITE 138 FF: RESIDUAL OIL-FIRED SOURCE*

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	MC
Thorium		Gadolinium		Molybdenum	0.2	Titanium	0.8
Bismuth		Europium		Niobium		Scandium	≤0.01
Lead	0.3	Samarium		Zirconium	0.05	Calcium	80[+]
Thallium		Neodymium		Yttrium	0.01	Potassium	4
Mercury	NR	Praseodymium	<0.01	Strontium	0.03[+]	Chlorine	1
Gold		Cerium	0.04	Rubidium	<0.01	Sulfur	44
Platinum		Lanthanum	0.03	Bromine		Phosphorus	1
Iridium		Barium	0.8	Selenium	0.04	Silicon	11
Osmium		Cesium		Arsenic	0.4	Aluminum	0.9
Rhenium		Iodine		Germanium	<0.01	Magnesium	7
Tungsten		Tellurium		Gallium	0.6	Sodium	>18
Tantalum		Antimony		Zinc	1	Fluorine	≈2
Hafnium		Tin	0.03	Copper	0.8	Oxygen	NR
Lutetium		Indium	STD	Nickel	73	Nitrogen	NR
Ytterbium		Cadmium	0.02	Cobalt	2	Carbon	NR
Thulium		Silver	0.1	Iron	17	Boron	≤0.01
Erbium		Palladium		Manganese	0.1[+]	Beryllium	
Holmium		Rhodium		Chromium	0.2	Lithium	0.02
Dysprosium						Hydrogen	NR

NR – Not Reported
All elements not detected <0.01 ppm weight
MC – Major Component

Approved:

*Analysis by Commercial Testing and Engineering Co., Golden, Colorado.

[+] Heterogeneous

SITE 139 AND 140 FF: DISTILLATE OIL-FIRED SOURCES*

CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	1
Thorium		Gadolinium		Molybdenum	0.7†	Titanium	2
Bismuth	0.5†	Europium		Niobium		Scandium	$\leq$0.02
Lead	2	Samarium		Zirconium	0.09	Calcium	77
Thallium		Neodymium		Yttrium		Potassium	0.4
Mercury	NR	Praseodymium		Strontium	0.4	Chlorine	0.2†
Gold		Cerium		Rubidium	0.08	Sulfur	>84
Platinum		Lanthanum		Bromine	0.5	Phosphorus	MC
Iridium		Barium	15	Selenium	0.2	Silicon	5
Osmium		Cesium		Arsenic	0.1	Aluminum	0.3
Rhenium		Iodine	0.02	Germanium	<0.01	Magnesium	2
Tungsten		Tellurium		Gallium	0.03†	Sodium	2
Tantalum		Antimony	0.08	Zinc	0.6	Fluorine	≈0.1
Hafnium		Tin	0.1	Copper	11	Oxygen	NR
Lutetium		Indium	STD	Nickel	1	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	0.1	Carbon	NR
Thulium		Silver		Iron	33	Boron	0.1
Erbium		Palladium		Manganese	0.3	Beryllium	
Holmium		Rhodium		Chromium	2	Lithium	<0.01
Dysprosium						Hydrogen	NR

NR – Not Reported

All elements not detected <0.01 ppm weight

Approved: M J Jacobs

MC – Major Component

*Analysis by Commercial Testing and Engineering Co., Golden, Colorado.

†Heterogeneous

	SITE 346: RESIDUAL OIL		SITE 337: RESIDUAL OIL-FIRED		SITE 339: DISTILLATE OIL-FIRED	
ELEMENT	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.73	< 0.0066	< 0.93	< 0.030	< 1.3	< 0.056
TH	< 1.1	< 0.0095	< 1.4	< 0.044	< 1.9	< 0.081
BI	< 0.33	< 0.0030	< 0.42	< 0.014	< 0.59	< 0.025
PB	3.1	0.028	< 0.87	< 0.028	< 1.2	< 0.052
TL	< 0.41	< 0.0037	< 0.52	< 0.017	< 0.74	< 0.031
AU	< 0.55	< 0.0049	< 0.70	< 0.023	< 0.99	< 0.042
IR	< 0.84	< 0.0076	< 1.1	< 0.035	< 1.5	< 0.064
OS	< 0.92	< 0.0082	< 1.2	< 0.038	< 1.7	< 0.070
RE	< 0.58	< 0.0052	< 0.74	< 0.024	< 1.0	< 0.044
W	< 0.78	< 0.0070	< 0.99	< 0.032	< 1.4	< 0.059
HF	< 0.97	< 0.0087	< 1.2	< 0.040	< 1.8	< 0.074
LU	< 0.23	< 0.0020	< 0.29	< 0.0094	< 0.41	< 0.017
YB	< 0.33	< 0.0030	< 0.42	< 0.014	< 0.60	< 0.025
TM	< 0.20	< 0.0018	< 0.26	< 0.0083	< 0.36	< 0.015
ER	< 0.59	< 0.0053	< 0.76	< 0.024	< 1.1	< 0.045
HO	< 0.19	< 0.0018	< 0.25	< 0.0080	< 0.35	< 0.015
DY	< 0.34	< 0.0031	< 0.43	< 0.014	< 0.61	< 0.026
TB	< 0.092	< 0.0008	< 0.12	< 0.0038	< 0.17	< 0.0070
GD	< 0.34	< 0.0030	< 0.43	< 0.014	< 0.61	< 0.026
EU	< 0.15	< 0.0014	< 0.19	< 0.0063	< 0.28	< 0.012
SM	< 0.59	< 0.0053	< 0.75	< 0.024	< 1.1	< 0.045
ND	< 0.74	< 0.0066	< 0.94	< 0.030	< 1.3	< 0.056
PR	< 0.13	< 0.0012	< 0.17	< 0.0054	< 0.24	< 0.0099
CE	< 0.18	< 0.0016	< 0.22	< 0.0072	< 0.32	< 0.013
LA	< 0.19	< 0.0017	< 0.24	< 0.0079	< 0.34	< 0.015
BA	1.0	0.0090	0.23	0.0076	1.3	0.057
CS	< 0.031	< 0.0003	< 0.039	< 0.0013	< 0.055	< 0.0023
I	< 0.71	< 0.0064	< 0.64	< 0.021	< 0.91	< 0.039
TE	< 0.43	< 0.0038	< 0.54	< 0.018	< 0.77	< 0.033
SB	< 0.30	< 0.0027	< 0.38	< 0.012	< 0.53	< 0.023
SN	< 0.42	< 0.0038	< 0.53	< 0.017	< 0.76	< 0.032
CD	< 0.52	< 0.0047	< 0.94	< 0.031	< 0.95	< 0.040
PD	< 0.42	< 0.0038	< 0.54	< 0.017	< 0.77	< 0.032
RH	-	-	< 0.19	< 0.0061	< 0.27	< 0.011

ELEMENT	SITE 346: RESIDUAL OIL-FIRED		SITE 337: RESIDUAL OIL-FIRED		SITE 339: DISTILLATE OIL-FIRED	
	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.54	< 0.0049	< 0.69	< 0.022	< 0.98	< 0.042
MO	< 0.50	< 0.0045	< 0.64	< 0.021	< 0.91	< 0.036
NB	< 0.063	< 0.0006	< 0.081	< 0.0026	< 0.11	< 0.0048
ZR	< 0.24	< 0.0021	< 0.30	< 0.0098	< 0.43	< 0.016
Y	< 0.098	< 0.0009	< 0.12	< 0.0040	< 0.18	< 0.0075
SR	0.33	0.0030	< 0.16	< 0.0050	< 0.22	< 0.0093
RB	0.030	0.0003	< 0.038	< 0.0012	< 0.054	< 0.0023
BR	< 0.76	< 0.0068	< 0.92	< 0.030	< 1.3	< 0.055
SE	< 0.29	< 0.0026	< 0.37	< 0.012	< 0.52	< 0.022
AS	0.23	0.0020	< 0.14	< 0.0047	< 0.21	< 0.0087
GE	< 0.20	< 0.0018	< 0.26	< 0.0084	< 0.37	< 0.016
GA	< 0.083	< 0.0007	< 0.11	< 0.0034	< 0.15	< 0.0063
ZN	3.0	0.027	5.0	0.16	5.8	0.24
CU	2.6	0.024	9.5	0.31	5.5	0.23
NI	10.	0.094	16.	0.52	18.	0.76
CO	0.61	0.0055	0.100	0.0034	0.15	0.0062
FE	5.0	0.045	4.8	0.16	3.2	0.14
MN	0.12	0.0010	0.18	0.0057	0.25	0.011
CR	0.50	0.0045	0.33	0.011	0.80	0.034
V	35.	0.31	44.	1.4	2.7	0.11
TI	0.79	0.0071	0.100	0.0033	< 0.21	< 0.0088
CA	5.0	0.045	5.6	0.18	2.6	0.11
K	3.6	0.032	30.	0.98	10.	0.42
S	420.	3.8	0.14 (%)	47.	720.	30.
P	5.5	0.049	4.7	0.15	< 0.084	< 0.0035
SI	76.	0.68	55.	1.8	18.	0.74
AL	< 4.8	< 0.043	2.8	0.090	2.0	0.083
MG	7.8	0.071	5.7	0.18	1.5	0.062
NA	30.	0.27	30.	0.99	13.	0.55
F	< 2.7	< 0.024	3.6	0.12	2.4	0.100
B	2.0	0.018	< 0.022	< 0.0007	< 0.031	< 0.0013
BE	< 0.0042	< 0.0001	< 0.0054	< 0.0002	< 0.0076	< 0.0003
LI	< 0.0020	< 0.0001	0.13	0.0043	0.094	0.0040

ANTHRACITE STOKERS

SITE 320: ANTHRACITE STOKER

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	XAD RESIN (MG)	COMP SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.13	0.016	< 0.048	< 0.0007	0.016 TO 0.17	0.0006 TO 0.0062	< 2.3	< 0.067
TH	< 0.37	0.0086	< 0.070	< 0.0010	0.0086 TO 0.44	0.0003 TO 0.016	< 3.3	< 0.097
BI	< 0.033	0.029	< 0.022	< 0.0003	0.029	0.0010	< 1.0	< 0.030
PB	0.53	1.4	< 1.1	< 0.012	1.9	0.067	< 12.	< 0.55
TL	< 0.040	0.030	< 0.027	< 0.0004	0.030 TO 0.068	0.0011 TO 0.0024	< 1.3	< 0.038
AU	< 0.051	< 0.0022	< 0.036	< 0.0005	< 0.090	< 0.0032	< 1.7	< 0.050
IR	< 0.078	< 0.0034	< 0.056	< 0.0008	< 0.14	< 0.0049	< 2.6	< 0.077
OS	< 0.085	< 0.0037	< 0.061	< 0.0009	< 0.15	< 0.0053	< 2.9	< 0.084
RE	< 0.054	< 0.0024	< 0.038	< 0.0005	< 0.095	< 0.0034	< 1.8	< 0.053
W	0.048	< 0.0063	< 0.052	< 0.0014	0.048	0.0017	< 28.	< 0.83
HF	< 0.12	< 0.0039	< 0.064	< 0.0009	< 0.19	< 0.0066	< 3.0	< 0.089
LU	< 0.028	< 0.0009	< 0.015	< 0.0002	< 0.045	< 0.0016	< 0.71	< 0.021
YB	< 0.031	< 0.0013	< 0.022	< 0.0003	< 0.054	< 0.0019	< 1.0	< 0.030
TM	< 0.019	< 0.0008	< 0.013	< 0.0002	< 0.033	< 0.0012	< 0.63	< 0.018
ER	< 0.055	< 0.0024	< 0.039	< 0.0006	< 0.097	< 0.0034	< 1.8	< 0.054
HO	< 0.017	< 0.0008	< 0.013	< 0.0002	< 0.031	< 0.0011	< 0.61	< 0.018
DY	0.071	0.0031	< 0.022	< 0.0003	0.074	0.0026	< 1.1	< 0.031
TB	< 0.0071	0.0004	< 0.0061	< 0.0001	0.0004 TO 0.013	< 0.0001 TO 0.0005	< 0.29	< 0.0084
GD	< 0.031	< 0.0014	< 0.022	< 0.0003	< 0.055	< 0.0019	< 1.0	< 0.031
EU	< 0.017	< 0.0006	< 0.0100	< 0.0001	< 0.028	< 0.0010	< 0.48	< 0.014
SM	0.072	0.0028	< 0.039	< 0.0005	0.075	0.0026	< 1.8	< 0.054
ND	0.24	0.014	< 0.049	< 0.0007	0.26	0.0091	< 2.3	< 0.067
PR	0.090	0.0021	< 0.0086	< 0.0001	0.093	0.0033	< 0.41	< 0.012
CE	0.98	0.031	< 0.033	< 0.0002	1.0	0.035	0.77	0.022
LA	0.50	0.023	< 0.013	< 0.0002	0.52	0.018	0.83	0.024
BA	5.8	0.53	< 0.58	< 0.0020	6.3	0.22	14.	0.40
CS	0.030	0.0009	< 0.0040	< 0.0001	0.031	0.0011	< 0.095	< 0.0028
I	0.034	< 0.0021	< 0.033	< 0.0005	0.034	0.0012	< 1.6	< 0.046
TE	< 0.039	0.0032	< 0.028	< 0.0004	0.0032 TO 0.068	0.0001 TO 0.0024	< 1.3	< 0.039
SB	0.027	0.050	< 0.020	< 0.0011	0.077	0.0027	0.91	0.027
SN	0.048	0.13	0.15	< 0.012	0.34	0.012	1.2	0.036
CD	0.015	0.014	< 0.035	< 0.0031	0.029	0.0010	< 1.6	< 0.048
PD	< 0.039	0.0013	< 0.028	< 0.0008	0.0013 TO 0.068	< 0.0001 TO 0.0024	< 1.3	< 0.039
RH	< 0.014	< 0.0006	< 0.0098	< 0.0001	< 0.024	< 0.0008	< 0.46	< 0.013

SITE 320: ANTHRACITE STOKER

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	XAD RESIN (MG)	COMP SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.042	< 0.0022	< 0.036	< 0.0005	< 0.081	< 0.0029	< 1.7	< 0.050
MO	0.12	0.25	0.093	0.035	0.49	0.017	< 1.6	< 0.046
NB	0.22	0.0007	0.0059	< 0.0001	0.23	0.0080	< 0.39	< 0.011
ZR	2.4	0.027	< 0.016	< 0.0029	2.4	0.085	1.5	0.043
Y	0.53	0.017	< 0.0065	< 0.0001	0.55	0.019	0.85	0.025
SR	1.4	0.12	0.066	0.0007	1.5	0.054	4.4	0.13
RB	0.51	0.014	< 0.023	0.0002	0.53	0.019	0.38	0.011
BR	0.13	0.0042	0.29	< 0.0019	0.43	0.015	< 4.6	< 0.14
SE	< 0.15	< 0.050	< 0.33	< 0.0032	< 0.54	< 0.019	< 5.0	< 0.15
AS	0.17	0.46	< 0.030	< 0.0006	0.63	0.022	1.5	0.043
GE	0.036	0.025	< 0.013	< 0.0002	0.061	0.0022	< 0.63	< 0.019
GA	0.45	1.0	< 0.0055	< 0.0006	1.5	0.053	1.5	0.044
ZN	0.68	1.7	< 3.0	0.023	2.4	0.084	23.	0.67
CU	1.5	1.6	< 9.4	< 0.024	3.2 TO 9.4	0.11 TO 0.33	17.	0.50
NI	2.9	0.31	< 4.1	0.41	3.6	0.13	5.9	0.17
CO	0.86	0.082	< 0.063	0.012	0.96	0.034	1.4	0.041
FE	98.	11.	< 4.3	1.1	110.	3.9	130.	3.8
MN	0.40	0.029	< 0.40	0.012	0.44	0.016	< 3.6	< 0.100
CR	2.1	0.40	< 0.69	0.28	2.8	0.098	5.6	0.17
V	1.4	0.27	< 0.29	< 0.0011	1.6	0.058	3.3	0.096
TI	35.	0.89	< 0.12	0.0016	36.	1.3	62.	1.8
CA	22.	1.2	< 5.8	0.045	23.	0.82	95.	2.8
K	19.	1.9	< 7.0	0.64	22.	0.77	110.	3.1
S	360.	78.	< 99.	3.7	440.	16.	2.9	(%) 660.
P	4.3	4.4	< 1.5	< 0.030	8.7	0.31	35.	1.0
SI	570.	< 1.5	1.2	0.17	580.	20.	580.	17.
AL	MC	7.3	< 5.4	< 0.033	-	-	720.	21.
MG	9.2	0.37	< 1.5	0.074	9.6	0.34	47.	1.4
NA	3.9	< 0.48	< 12.	< 0.17	3.9 TO 13.	0.14 TO 0.45	150.	4.4
F	2.2	1.0	< 0.27	< 0.021	3.3	0.12	14.	0.41
B	0.90	< 0.39	0.0090	0.0007	0.91	0.032	< 1.2	< 0.035
BE	0.24	0.012	< 0.0040	< 0.0005	0.26	0.0090	0.22	0.0064
LI	2.1	0.065	< 0.0043	< 0.0001	2.2	0.077	1.5	0.044

MC INDICATES A MAJOR COMPONENT OF THE SAMPLE.

- INDICATES THAT THE TOTAL AND EMISSION VALUES WERE NOT CALCULATED OWING TO THE PRESENCE OF AN MC CONCENTRATION.

SITE 344: ANTHRACITE STOKER

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	0.038	0.024	< 0.026	0.062	0.0027	0.100	0.0024
TH	0.076	< 0.0046	< 0.038	0.076	0.0034	0.20	0.0050
BI	< 0.033	0.061	< 0.012	0.061	0.0027	< 0.090	< 0.0022
PB	0.30	3.0	< 0.097	3.3	0.14	1.7	0.042
TL	< 0.039	0.045	< 0.015	0.045	0.0020	< 0.11	< 0.0027
AU	< 0.048	< 0.0024	< 0.020	< 0.070	< 0.0031	< 0.15	< 0.0036
IR	< 0.074	< 0.0037	< 0.030	< 0.11	< 0.0047	< 0.23	< 0.0056
OS	< 0.080	< 0.0040	< 0.033	< 0.12	< 0.0051	< 0.25	< 0.0061
RE	< 0.051	0.0084	< 0.021	0.0084 TO 0.071	0.0004 TO 0.0032	< 0.16	< 0.0039
W	< 0.034	0.0100	< 0.028	0.0100 TO 0.062	0.0004 TO 0.0027	< 0.21	< 0.0052
HF	< 0.17	< 0.0042	< 0.035	< 0.21	< 0.0091	< 0.27	< 0.0065
LU	< 0.041	< 0.0010	< 0.0081	< 0.050	< 0.0022	< 0.062	< 0.0015
YB	< 0.030	< 0.0014	< 0.012	< 0.044	< 0.0019	< 0.090	< 0.0022
TM	< 0.018	< 0.0009	< 0.0072	< 0.026	< 0.0011	< 0.055	< 0.0013
ER	< 0.052	< 0.0026	< 0.021	< 0.076	< 0.0033	< 0.16	< 0.0040
HO	< 0.0085	< 0.0008	< 0.0069	< 0.016	< 0.0007	< 0.053	< 0.0013
DY	0.024	< 0.0066	< 0.012	0.024	0.0010	0.100	0.0025
TB	< 0.0057	0.0038	< 0.0033	0.0038 TO 0.0090	0.0002 TO 0.0004	0.013	0.0003
GD	< 0.029	< 0.0015	< 0.012	< 0.043	< 0.0019	< 0.092	< 0.0022
EU	< 0.021	< 0.0007	< 0.0054	< 0.027	< 0.0012	< 0.042	< 0.0010
SM	< 0.062	< 0.0026	< 0.021	< 0.086	< 0.0038	< 0.16	< 0.0039
ND	0.14	< 0.0032	< 0.026	0.14	0.0062	0.46	0.011
PR	0.023	0.0005	< 0.0046	0.023	0.0010	0.036	0.0009
CE	0.23	0.011	< 0.0063	0.24	0.011	0.26	0.0064
LA	0.23	0.0060	< 0.0068	0.24	0.011	0.21	0.0051
BA	2.7	6.7	< 0.074	9.5	0.42	13.	0.33
CS	0.011	0.016	< 0.0011	0.026	0.0012	0.063	0.0015
I	< 0.039	0.0088	< 0.018	0.0088 TO 0.057	0.0004 TO 0.0025	< 0.28	< 0.0067
TE	< 0.036	0.0080	< 0.015	0.0080 TO 0.051	0.0003 TO 0.0023	< 0.12	< 0.0028
SB	0.052	0.15	< 0.011	0.21	0.0091	< 0.081	< 0.0020
SN	0.031	0.43	< 0.89	0.46	0.020	0.11	0.0028
CD	< 0.0085	0.025	< 0.0070	0.025	0.0011	0.14	0.0034
PD	< 0.050	< 0.0018	< 0.015	< 0.067	< 0.0029	< 0.12	< 0.0028

SITE 344: ANTHRACITE STOKER

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.040	< 0.0024	< 0.019	< 0.062	< 0.0027	< 0.15	< 0.0036
MO	0.044	0.33	2.7	3.1	0.14	0.55	0.013
NB	0.074	0.0004	< 0.0023	0.074	0.0033	0.050	0.0012
ZR	0.67	0.0067	< 0.0085	0.68	0.030	0.91	0.022
Y	0.14	0.0043	< 0.0035	0.14	0.0064	0.20	0.0049
SR	1.3	0.11	< 0.017	1.4	0.061	8.0	0.19
RB	0.19	0.12	< 0.0060	0.32	0.014	0.69	0.017
BR	0.39	1.6	< 0.054	2.0	0.089	< 0.41	< 0.0100
SE	0.11	0.32	0.055	0.48	0.021	0.73	0.018
AS	0.68	0.99	0.030	1.7	0.075	1.9	0.045
GE	0.022	0.026	< 0.0072	0.048	0.0021	< 0.056	< 0.0014
GA	0.21	1.4	0.0042	1.7	0.073	0.75	0.018
ZN	0.38	9.0	6.9	16.	0.72	3.3	0.079
CU	0.62	3.1	1.4	5.1	0.23	2.9	0.070
NI	1.3	0.18	6.2	7.7	0.34	1.3	0.033
CO	0.22	0.042	0.34	0.60	0.027	0.33	0.0081
FE	150.	6.0	25.	180.	8.1	71.	1.7
MN	0.43	0.14	0.61	1.2	0.052	0.54	0.013
CR	0.28	0.61	9.9	11.	0.48	2.3	0.055
V	0.91	0.30	0.033	1.2	0.055	2.3	0.056
TI	33.	0.42	0.029	33.	1.5	37.	0.90
SC	0.17	0.0026	< 0.0010	0.18	0.0078	0.17	0.0041
CA	18.	< 1.9	1.1	19.	0.82	56.	1.4
K	35.	57.	< 4.3	92.	4.1	57.	1.4
S	110.	160.	62.	330.	15.	0.14 (%)	33.
P	16.	54.	< 0.40	70.	3.1	6.2	0.15
SI	470.	0.76	< 1.5	470.	21.	380.	9.3
AL	650.	27.	< 0.71	680.	30.	350.	8.5
MG	7.5	7.9	0.46	16.	0.70	18.	0.45
NA	82.	MC	5.2	-	-	34.	0.83
F	10.	0.17	< 0.051	10.	0.46	< 5.8	< 0.14
B	9.9	36.	< 0.026	46.	2.0	0.55	0.013
BE	0.073	0.0044	< 0.0005	0.078	0.0034	0.025	0.0006
LI	2.2	0.28	0.0027	2.5	0.11	0.76	0.019

MC INDICATES A MAJOR COMPONENT OF THE SAMPLE.

- INDICATES THAT THE TOTAL AND EMISSION VALUES WERE NOT CALCULATED OWING TO THE PRESENCE OF AN MC CONCENTRATION.

SITE 345: ANTHRACITE STOKER

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	0.0042	0.015	< 0.044	0.019 TO 0.044	0.0010 TO 0.0024	< 0.40	< 0.014
TH	0.0084	< 0.0029	< 0.064	0.0084 TO 0.067	0.0005 TO 0.0036	< 0.58	< 0.020
BI	0.0036	0.027	< 0.020	0.031	0.0017	< 0.18	< 0.0063
PB	0.17	2.7	< 0.058	2.8	0.15	1.7	0.061
TL	0.059	0.040	< 0.025	0.099	0.0054	< 0.22	< 0.0079
AU	< 0.0075	< 0.0015	< 0.033	< 0.042	< 0.0023	< 0.30	< 0.011
IR	< 0.011	< 0.0023	< 0.051	< 0.065	< 0.0035	< 0.46	< 0.016
OS	< 0.012	< 0.0025	< 0.055	< 0.070	< 0.0038	< 0.50	< 0.018
RE	< 0.0079	< 0.0016	< 0.035	< 0.045	< 0.0024	< 0.32	< 0.011
W	< 0.0053	0.013	< 0.047	0.013 TO 0.052	0.0007 TO 0.0028	< 0.42	< 0.015
HF	< 0.026	< 0.0027	< 0.059	< 0.087	< 0.0047	< 0.53	< 0.019
LU	< 0.0064	< 0.0006	< 0.014	< 0.021	< 0.0011	< 0.12	< 0.0044
YB	< 0.0047	< 0.0009	< 0.020	< 0.026	< 0.0014	< 0.18	< 0.0063
TM	< 0.0028	< 0.0005	< 0.012	< 0.016	< 0.0008	< 0.11	< 0.0039
ER	< 0.0081	< 0.0016	< 0.036	< 0.046	< 0.0025	< 0.32	< 0.011
HO	< 0.0013	< 0.0005	< 0.012	< 0.014	< 0.0007	< 0.11	< 0.0037
DY	0.0026	< 0.0009	< 0.021	0.0026 TO 0.021	0.0001 TO 0.0012	< 0.18	< 0.0065
TB	< 0.0009	< 0.0002	< 0.0056	< 0.0067	< 0.0004	< 0.050	< 0.0018
GD	< 0.0046	< 0.0009	< 0.020	< 0.026	< 0.0014	< 0.18	< 0.0065
EU	< 0.0032	< 0.0004	< 0.0092	< 0.013	< 0.0007	< 0.083	< 0.0029
SM	< 0.0097	< 0.0016	< 0.036	< 0.047	< 0.0026	< 0.32	< 0.011
ND	0.015	0.0033	< 0.045	0.018 TO 0.045	0.0010 TO 0.0024	0.32	0.011
PR	0.0035	0.0007	< 0.0079	0.0043	0.0002	0.071	0.0025
CE	0.036	0.0072	< 0.011	0.043	0.0023	0.72	0.025
LA	0.051	0.0039	< 0.012	0.055	0.0030	0.30	0.0100
BA	0.85	0.081	< 0.090	0.93	0.051	27.	0.95
CS	0.0063	0.014	< 0.0018	0.021	0.0011	0.033	0.0012
I	< 0.012	< 0.0014	< 0.031	< 0.044	< 0.0024	< 0.27	< 0.0097
TE	< 0.0056	0.0050	< 0.026	0.0050 TO 0.031	0.0003 TO 0.0017	< 0.23	< 0.0082
SB	0.016	0.19	< 0.018	0.21	0.011	0.080	0.0028
SN	0.014	0.28	< 0.20	0.29	0.016	< 0.23	< 0.0081
CD	0.0004	0.015	< 0.032	0.016 TO 0.032	0.0008 TO 0.0017	< 0.29	< 0.0100
PD	< 0.0077	< 0.0012	< 0.026	< 0.035	< 0.0019	< 0.23	< 0.0082

SITE 345: ANTHRACITE STOKER

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0062	< 0.0015	< 0.033	< 0.041	< 0.0022	< 0.30	< 0.0100
MO	0.019	0.29	0.57	0.88	0.048	0.34	0.012
NB	0.022	0.0003	< 0.0038	0.022	0.0012	0.024	0.0009
ZR	0.21	0.0091	< 0.014	0.22	0.012	0.90	0.032
Y	0.044	0.0020	< 0.0059	0.046	0.0025	0.29	0.0100
SR	0.55	0.040	< 0.029	0.59	0.032	16.	0.56
RB	0.061	0.16	< 0.0051	0.22	0.012	0.48	0.017
BR	0.24	0.0057	< 0.18	0.25	0.013	< 0.58	< 0.021
SE	0.033	0.100	0.018	0.15	0.0082	1.4	0.051
AS	0.43	1.2	0.072	1.7	0.095	1.9	0.066
GE	0.0068	0.014	< 0.012	0.021	0.0011	0.078	0.0028
GA	0.19	0.91	0.0035	1.1	0.060	0.68	0.024
ZN	0.24	4.4	< 0.72	4.6	0.25	1.6	0.057
CU	0.27	2.2	< 0.64	2.5	0.13	2.9	0.100
NI	0.41	0.23	11.	11.	0.61	1.3	0.047
CO	0.13	0.027	0.14	0.31	0.017	1.3	0.047
FE	48.	7.6	16.	71.	3.9	97.	3.4
MN	0.28	0.094	1.0	1.4	0.077	0.78	0.028
CR	0.26	0.38	8.4	9.0	0.49	4.5	0.16
V	0.20	0.27	0.018	0.49	0.027	2.3	0.080
TI	10.	0.27	0.037	11.	0.57	38.	1.3
SC	0.054	< 0.0001	< 0.0017	0.054	0.0029	0.47	0.017
CA	12.	3.2	< 3.2	16.	0.85	170.	6.0
K	16.	38.	< 3.7	54.	2.9	33.	1.2
S	34.	100.	270.	410.	22.	0.27 (%)	95.
P	5.1	32.	< 0.96	37.	2.0	25.	0.89
SI	**	0.90	19.	**	68.	380.	13.
AL	610.	6.7	< 2.4	620.	34.	170.	5.9
MG	2.3	1.2	1.9	5.4	0.29	24.	0.86
NA	53.	MC	14.	-	-	< 4.2	< 0.15
F	1.5	< 0.0073	< 0.32	1.5	0.084	2.1	0.075
B	0.74	0.73	0.023	1.5	0.081	0.27	0.0096
BE	0.0081	0.0014	< 0.0005	0.0095	0.0005	0.034	0.0012
LI	0.12	0.057	0.0047	0.18	0.0099	1.5	0.054

MC INDICATES A MAJOR COMPONENT OF THE SAMPLE.

- INDICATES THAT THE TOTAL AND EMISSION VALUES WERE NOT CALCULATED OWING TO THE PRESENCE OF AN MC CONCENTRATION.

** INDICATES A VALUE EXCEEDING ONE GRAM.

BITUMINOUS STOKERS

SITE 220: BITUMINOUS STOKER, UNDERFEED

ELEMENT	10+3UM CYLLONE (MG)	PF+1UM CYCLONE (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0001	< 0.0023	< 0.0083	< 0.0001 TO 0.011	< 0.0001 TO 0.0003	< 0.23	< 0.011
TH	< 0.0001	< 0.0033	< 0.012	< 0.0001 TO 0.015	< 0.0001 TO 0.0005	< 0.33	< 0.015
BI	< 0.0001	0.0020	< 0.0037	0.0020	< 0.0001	< 0.100	< 0.0048
PB	0.0053	0.29	0.0077	0.30	0.0097	0.60	0.028
TL	< 0.0001	0.0095	< 0.0047	0.0096	0.0003	< 0.13	< 0.0060
AU	< 0.0001	< 0.0017	< 0.0062	< 0.0079	< 0.0002	< 0.17	< 0.0080
IR	< 0.0001	< 0.0026	< 0.0096	< 0.012	< 0.0004	< 0.26	< 0.012
OS	< 0.0001	< 0.0028	< 0.0100	< 0.013	< 0.0004	< 0.28	< 0.013
RE	< 0.0001	< 0.0018	< 0.0066	< 0.0001 TO 0.0084	< 0.0001 TO 0.0003	< 0.18	< 0.0085
W	< 0.0001	< 0.0024	< 0.0088	< 0.0001 TO 0.011	< 0.0001 TO 0.0004	0.18	0.0087
HF	< 0.0001	< 0.0030	< 0.011	< 0.014	< 0.0004	< 0.30	< 0.014
LU	< 0.0001	< 0.0007	< 0.0026	< 0.0033	< 0.0001	< 0.070	< 0.0033
YB	< 0.0001	< 0.0010	< 0.0037	< 0.0001 TO 0.0048	< 0.0001 TO 0.0001	< 0.100	< 0.0048
TM	< 0.0001	< 0.0006	< 0.0023	< 0.0001 TO 0.0029	< 0.0001 TO 0.0001	< 0.062	< 0.0029
ER	< 0.0001	< 0.0018	< 0.0067	< 0.0001 TO 0.0086	< 0.0001 TO 0.0003	< 0.18	< 0.0086
HO	< 0.0001	< 0.0006	< 0.0022	< 0.0001 TO 0.0028	< 0.0001 TO 0.0001	< 0.060	< 0.0028
DY	< 0.0001	< 0.0010	< 0.0039	< 0.0001 TO 0.0049	< 0.0001 TO 0.0002	0.074	0.0035
TB	< 0.0001	< 0.0003	< 0.0010	< 0.0001 TO 0.0013	< 0.0001 TO 0.0001	< 0.028	< 0.0013
GD	< 0.0001	< 0.0010	< 0.0038	< 0.0001 TO 0.0049	< 0.0001 TO 0.0002	< 0.100	< 0.0049
EU	< 0.0001	< 0.0005	< 0.0017	< 0.0001 TO 0.0022	< 0.0001 TO 0.0001	< 0.047	< 0.0022
SM	0.0001	< 0.0018	< 0.0067	0.0001 TO 0.0085	< 0.0001 TO 0.0003	0.15	0.0072
ND	0.0003	< 0.0023	< 0.0084	0.0003 TO 0.011	< 0.0001 TO 0.0003	0.26	0.012
PR	< 0.0001	< 0.0004	< 0.0015	< 0.0001 TO 0.0019	< 0.0001 TO 0.0001	0.16	0.0076
CE	0.0009	0.0011	< 0.0020	0.0020	< 0.0001	1.2	0.055
LA	0.0010	0.0004	< 0.0022	0.0014	< 0.0001	0.62	0.029
BA	0.025	< 0.041	< 0.012	0.025 TO 0.053	0.0008 TO 0.0017	15.	0.71
CS	< 0.0001	0.0004	< 0.0006	0.0004	< 0.0001	0.0094	0.0004
I	< 0.0001	0.0031	0.026	0.029	0.0009	0.62	0.029
TE	< 0.0001	< 0.0013	< 0.0048	< 0.0062	< 0.0002	< 0.13	< 0.0062
SB	0.0002	0.014	< 0.0034	0.014	0.0004	< 0.091	< 0.0043
SN	0.0002	0.30	< 0.0048	0.30	0.0096	0.17	0.0083
CD	< 0.0001	0.0018	< 0.0060	0.0019 TO 0.0060	< 0.0001 TO 0.0002	0.16	0.0076
PD	< 0.0001	< 0.0013	< 0.0048	< 0.0001 TO 0.0061	< 0.0001 TO 0.0002	< 0.13	< 0.0062
RH	< 0.0001	< 0.0005	< 0.0017	< 0.0021	< 0.0001	< 0.045	< 0.0022

SITE 220: BITUMINOUS STOKER

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0001	< 0.0017	< 0.0062	< 0.0079	< 0.0002	< 0.17	< 0.0079
MO	0.0021	0.0085	0.086	0.096	0.0031	0.31	0.015
NB	0.0002	< 0.0002	< 0.0007	0.0002 TO 0.0009	< 0.0001 TO 0.0001	0.0097	0.0005
ZR	0.0023	0.0011	< 0.0027	0.0034	0.0001	1.1	0.052
Y	0.0023	0.0012	< 0.0011	0.0035	0.0001	0.90	0.043
SR	0.032	0.032	< 0.0014	0.064	0.0020	37.	1.8
RB	0.0006	0.0029	< 0.0006	0.0034	0.0001	0.20	0.0092
BR	0.0049	0.0061	0.011	0.023	0.0007	0.93	0.044
SE	0.0008	0.043	< 0.0033	0.044	0.0014	1.1	0.054
AS	0.0041	0.083	0.019	0.11	0.0034	8.4	0.40
GE	0.0008	0.038	< 0.0023	0.038	0.0012	0.12	0.0059
GA	0.0009	0.047	< 0.0009	0.048	0.0015	0.29	0.014
ZN	0.015	0.17	0.025	0.21	0.0067	0.71	0.033
CU	0.012	0.087	0.026	0.12	0.0040	1.7	0.081
NI	0.063	0.043	0.65	0.76	0.024	1.1	0.050
CO	0.0026	0.0027	0.0095	0.015	0.0005	0.37	0.018
FE	1.8	0.47	2.0	4.2	0.14	430.	20.
MN	0.042	0.0069	0.046	0.094	0.0030	0.58	0.027
CR	0.030	0.0092	0.42	0.46	0.015	0.88	0.042
V	0.0038	0.0015	0.0011	0.0065	0.0002	0.63	0.030
TI	0.047	0.0077	0.0052	0.060	0.0019	15.	0.70
CA	2.9	< 2.4	< 0.31	2.9	0.092	150.	7.0
K	0.42	< 2.6	0.11	0.53 TO 2.6	0.017 TO 0.083	22.	1.0
S	0.42	15.	8.8	24.	0.78	0.29 (%)	140.
P	0.13	19.	0.026	19.	0.61	3.1	0.15
SI	2.3	2.7	0.67	5.7	0.18	690.	32.
AL	1.1	1.9	0.093	3.1	0.099	200.	9.6
MG	0.33	< 0.42	0.065	0.40	0.013	55.	2.6
NA	0.088	< 0.36	0.54	0.63	0.020	12.	0.59
F	0.11	< 0.066	< 0.17	0.11 TO 0.24	0.0035 TO 0.0076	< 9.2	< 0.44
B	0.028	< 0.072	0.0013	0.030 TO 0.072	0.0009 TO 0.0023	< 0.17	< 0.0079
BE	0.0018	0.0004	< 0.0006	0.0022	< 0.0001	0.077	0.0037
LI	0.0064	0.0038	< 0.0027	0.0100	0.0003	0.43	0.020

SITE 325: BITUMINOUS STOKER (SPREADER)

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	XAD RESIN (MG)	COMP SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	0.035	< 0.026	< 0.077	< 0.0013	0.035 TO 0.100	0.0011 TO 0.0035	< 3.1	< 0.100
TH	0.15	0.0095	< 0.11	< 0.0019	0.16	0.0052	< 4.4	< 0.15
BI	0.0062	0.044	< 0.035	< 0.0006	0.050	0.0017	< 1.4	< 0.047
PB	0.31	1.7	< 0.59	< 0.0079	2.0	0.066	8.0	0.27
TL	< 0.0038	0.065	< 0.043	< 0.0007	0.065	0.0022	< 1.7	< 0.059
AU	< 0.0048	< 0.0024	< 0.058	< 0.0010	< 0.066	< 0.0022	< 2.3	< 0.078
IR	< 0.0074	< 0.0038	< 0.089	< 0.0015	< 0.100	< 0.0034	< 3.5	< 0.12
OS	< 0.0080	< 0.0041	< 0.097	< 0.0016	< 0.11	< 0.0037	< 3.8	< 0.13
RE	< 0.042	< 0.0026	< 0.061	< 0.0010	< 0.11	< 0.0035	< 2.4	< 0.083
W	0.0091	0.0025	< 0.082	< 0.0039	0.012 TO 0.086	0.0004 TO 0.0029	< 9.1	< 0.31
HF	< 0.011	< 0.0043	< 0.100	< 0.0017	< 0.12	< 0.0040	< 4.1	< 0.14
LU	< 0.0027	< 0.0010	< 0.024	< 0.0004	< 0.028	< 0.0009	< 0.95	< 0.032
YB	< 0.016	< 0.0015	< 0.035	< 0.0006	< 0.053	< 0.0018	< 1.4	< 0.047
TM	< 0.0018	< 0.0009	< 0.021	< 0.0004	< 0.024	< 0.0008	< 0.84	< 0.029
ER	< 0.036	< 0.0026	< 0.063	< 0.0011	< 0.100	< 0.0034	< 2.5	< 0.085
HO	< 0.013	< 0.0012	< 0.021	< 0.0003	< 0.035	< 0.0012	< 0.82	< 0.028
DY	< 0.017	0.0068	< 0.036	< 0.0006	0.0068 TO 0.053	0.0002 TO 0.0018	< 1.4	< 0.048
TB	< 0.022	0.0008	< 0.0097	< 0.0002	0.0008 TO 0.032	< 0.0001 TO 0.0011	< 0.39	< 0.013
GD	0.015	0.0021	< 0.036	< 0.0006	0.017 TO 0.036	0.0006 TO 0.0012	< 1.4	< 0.048
EU	0.0044	0.0005	< 0.016	< 0.0003	0.0049 TO 0.016	0.0002 TO 0.0005	< 0.64	< 0.022
SM	0.056	0.0053	< 0.062	< 0.0011	0.061	0.0020	< 2.5	< 0.084
ND	0.20	0.021	< 0.078	< 0.0013	0.22	0.0073	< 3.1	< 0.11
PR	0.038	0.0061	< 0.014	< 0.0002	0.044	0.0015	0.54	0.018
CE	0.39	0.047	< 0.019	< 0.0003	0.43	0.014	4.3	0.15
LA	0.38	0.036	< 0.020	< 0.0003	0.42	0.014	4.6	0.16
BA	9.4	1.2	0.039	0.054	11.	0.35	81.	2.8
CS	0.017	0.0058	< 0.0038	< 0.0001	0.023	0.0008	0.26	0.0087
I	0.0067	< 0.0023	< 0.15	< 0.0013	0.0067 TO 0.15	0.0002 TO 0.0051	< 2.1	< 0.072
TE	< 0.0037	0.0035	< 0.045	< 0.0008	0.0035 TO 0.050	0.0001 TO 0.0016	< 1.8	< 0.061
SB	0.030	0.038	< 0.031	< 0.0021	0.068	0.0022	< 1.2	< 0.042
SN	0.073	0.21	< 0.044	< 0.024	0.28	0.0093	< 3.3	< 0.11
CD	0.032	0.045	< 0.055	< 0.0038	0.077	0.0026	2.2	0.074
PD	0.0100	< 0.0019	< 0.045	< 0.0021	0.0100 TO 0.049	0.0003 TO 0.0016	< 1.8	< 0.060
RH	< 0.0013	< 0.0013	< 0.016	< 0.0003	< 0.019	< 0.0006	< 1.2	< 0.042

SITE 325: BITUMINOUS STOKER (SPREADER)

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	XAD RESIN (MG)	COMP SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0040	< 0.0024	< 0.058	< 0.0010	< 0.065	< 0.0022	< 2.3	< 0.078
MO	0.033	0.048	< 0.053	0.19	0.27	0.0089	< 4.2	< 0.14
NB	0.17	0.0021	< 0.0067	0.0001	0.17	0.0057	1.5	0.053
ZR	0.87	0.030	< 0.025	< 0.0004	0.90	0.030	12.	0.40
Y	0.29	0.019	< 0.0100	< 0.0002	0.31	0.0100	2.4	0.081
SR	25.	2.2	< 0.025	0.0024	27.	0.90	180.	6.1
RB	0.28	0.065	< 0.0038	< 0.0001	0.34	0.011	2.9	0.099
BR	0.100	0.0096	< 0.43	< 0.0038	0.11 TO 0.43	0.0037 TO 0.014	< 12.	< 0.41
SE	< 0.12	< 0.055	< 0.39	< 0.013	< 0.58	< 0.019	< 10.	< 0.35
AS	1.1	1.0	< 0.012	< 0.0068	2.1	0.069	11.	0.38
GE	0.047	0.039	< 0.021	< 0.0004	0.086	0.0028	< 3.4	< 0.12
GA	0.25	1.1	< 0.0088	< 0.0006	1.3	0.043	5.8	0.20
ZN	0.13	1.8	< 0.81	< 0.081	2.0	0.066	22.	0.74
CU	0.87	1.8	< 1.0	< 0.046	2.6	0.087	19.	0.65
NI	0.40	0.21	< 0.43	0.68	1.3	0.043	19.	0.65
CO	0.17	0.13	< 0.012	0.017	0.31	0.0100	1.9	0.065
FE	440.	25.	< 2.4	2.3	470.	15.	0.14 (%)	47.
MN	2.3	0.30	< 0.085	0.081	2.7	0.089	12.	0.40
CR	0.37	0.31	< 0.18	0.75	1.4	0.047	9.5	0.32
V	0.70	0.14	< 0.043	0.0019	0.85	0.028	6.5	0.22
TI	54.	1.4	< 0.070	< 0.0048	55.	1.8	300.	10.
CA	170.	36.	< 5.1	0.15	210.	6.8	750.	26.
K	19.	22.	< 1.6	< 0.064	41.	1.4	300.	10.
S	50.	120.	< 41.	2.5	170.	5.7	0.49 (%)	170.
P	8.5	78.	< 0.86	0.13	86.	2.9	450.	15.
SI	130.	< 1.7	< 5.5	0.58	130.	4.4	0.32 (%)	110.
AL	30.	62.	< 2.1	0.038	92.	3.1	0.11 (%)	37.
MG	4.6	4.1	< 1.2	0.91	9.6	0.32	370.	13.
NA	11.	< 0.52	< 19.	0.16	11.	0.38	200.	6.9
F	9.0	1.6	< 1.3	< 0.078	11.	0.35	260.	8.7
B	1.3	0.44	0.0100	0.0100	1.7	0.057	< 13.	< 0.45
BE	0.045	0.013	< 0.0038	0.0009	0.060	0.0020	0.29	0.0100
LI	0.031	0.58	0.0017	< 0.0001	0.62	0.020	8.2	0.28

SITE 342: BITUMINOUS STOKER (OVERFEED)

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	0.016	0.19	< 0.041	0.21	0.0100	1.1	0.087
TH	0.023	< 0.0046	< 0.060	0.023 TO 0.065	0.0011 TO 0.0031	2.2	0.18
BI	0.0049	0.043	< 0.019	0.048	0.0023	< 0.17	< 0.014
PB	0.53	1.5	< 0.22	2.0	0.098	6.1	0.49
TL	0.0026	0.032	< 0.023	0.035	0.0017	< 0.21	< 0.017
AU	< 0.0002	< 0.0024	< 0.031	< 0.034	< 0.0016	< 0.28	< 0.023
IR	< 0.0004	< 0.0037	0.040	0.040	0.0019	< 0.44	< 0.035
OS	< 0.0004	< 0.0040	< 0.052	< 0.056	< 0.0027	< 0.47	< 0.038
RE	< 0.0003	< 0.0025	< 0.033	< 0.036	< 0.0017	< 0.30	< 0.024
W	0.0015	0.014	< 0.044	0.016 TO 0.044	0.0008 TO 0.0021	< 0.40	< 0.032
HF	0.0086	< 0.0042	< 0.055	0.0086 TO 0.059	0.0004 TO 0.0029	< 0.50	< 0.040
LU	0.0016	< 0.0010	< 0.013	0.0016 TO 0.014	< 0.0001 TO 0.0007	< 0.12	< 0.0094
YB	0.0023	< 0.0014	< 0.019	0.0023 TO 0.020	0.0001 TO 0.0010	0.34	0.027
TM	0.0007	< 0.0009	< 0.011	0.0007 TO 0.012	< 0.0001 TO 0.0006	0.100	0.0084
ER	0.0082	< 0.0026	< 0.034	0.0082 TO 0.036	0.0004 TO 0.0018	0.88	0.070
HO	0.0013	< 0.0008	< 0.011	0.0013 TO 0.012	< 0.0001 TO 0.0006	0.20	0.016
DY	0.0100	< 0.0048	< 0.019	0.0100 TO 0.024	0.0005 TO 0.0012	1.5	0.12
TB	0.0009	0.0009	< 0.0052	0.0017 TO 0.0052	< 0.0001 TO 0.0002	0.095	0.0076
GD	0.0035	< 0.0015	< 0.019	0.0035 TO 0.021	0.0002 TO 0.0010	0.39	0.032
EU	0.0008	< 0.0007	< 0.0086	0.0008 TO 0.0093	< 0.0001 TO 0.0004	0.086	0.0069
SM	0.018	< 0.0026	< 0.033	0.018	0.0009	1.2	0.093
ND	0.043	0.0100	< 0.042	0.053	0.0026	9.4	0.75
PR	0.014	0.0005	< 0.0074	0.014	0.0007	2.0	0.16
CE	0.15	0.011	< 0.0099	0.17	0.0080	7.7	0.61
LA	0.16	0.0058	< 0.011	0.16	0.0079	5.9	0.47
BA	0.63	< 7.2	< 0.059	0.63 TO 7.3	0.030 TO 0.35	100.	8.2
CS	0.0008	0.0078	< 0.0017	0.0086	0.0004	0.12	0.0095
I	< 0.0015	0.0010	< 0.029	0.0010 TO 0.030	< 0.0001 TO 0.0015	< 0.52	< 0.042
TE	0.0004	0.0040	< 0.024	0.0044 TO 0.024	0.0002 TO 0.0012	< 0.22	< 0.018
SB	0.0078	0.039	< 0.017	0.047	0.0023	0.31	0.024
SN	0.037	0.31	< 0.71	0.34 TO 0.71	0.017 TO 0.034	0.43	0.035
CD	< 0.0001	0.0100	0.022	0.032	0.0016	2.4	0.19
PD	< 0.0002	< 0.0018	< 0.024	< 0.026	< 0.0013	< 0.22	< 0.018

SITE 342: BITUMINOUS STOKER (OVERFEED)

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	0.0008	< 0.0024	< 0.031	0.0008 TO 0.033	< 0.0001 TO 0.0016	< 0.28	< 0.023
MO	0.0093	0.082	8.6	8.7	0.42	0.78	0.062
NB	0.011	< 0.0003	0.014	0.026	0.0012	0.49	0.039
ZR	0.46	0.0059	< 0.013	0.46	0.022	7.3	0.59
Y	0.19	0.0062	< 0.0055	0.19	0.0094	6.0	0.48
SR	0.61	< 0.13	< 0.039	0.61	0.029	130.	10.
RB	0.016	0.023	< 0.0017	0.039	0.0019	1.3	0.100
BR	0.016	0.025	0.12	0.16	0.0079	1.9	0.15
SE	0.016	0.63	0.049	0.70	0.034	3.3	0.26
AS	0.12	0.49	0.045	0.65	0.032	2.5	0.20
GE	0.077	0.031	< 0.011	0.11	0.0053	1.0	0.083
GA	0.14	1.0	0.0094	1.2	0.057	5.1	0.41
ZN	0.13	2.0	< 0.68	2.2	0.100	6.2	0.49
CU	0.20	3.1	0.88	4.2	0.20	11.	0.88
NI	0.44	0.38	39.	40.	2.0	11.	0.86
CO	0.036	0.18	1.1	1.4	0.066	1.3	0.100
FE	12.	8.6	160.	180.	8.6	720.	58.
MN	0.037	0.066	7.8	7.9	0.38	4.3	0.34
CR	0.095	0.30	50.	50.	2.4	13.	1.0
V	0.11	0.15	0.11	0.37	0.018	9.0	0.72
TI	3.8	0.100	0.32	4.2	0.20	210.	17.
SC	0.029	0.0012	< 0.0016	0.030	0.0015	1.3	0.100
CA	6.4	< 11.	< 6.0	6.4 TO 17.	0.31 TO 0.84	0.13 (%)	110.
K	3.0	18.	< 1.7	21.	1.0	220.	17.
S	5.9	160.	**	**	62.	1.4 (%)	**
P	2.7	19.	< 1.3	22.	1.1	48.	3.8
SI	42.	0.74	< 1.2	43.	2.1	0.33 (%)	260.
AL	MC	7.7	< 0.79	-	-	0.14 (%)	110.
MG	0.30	< 6.5	< 3.7	0.30 TO 10.	0.015 TO 0.49	140.	11.
NA	3.4	MC	< 6.6	-	-	66.	5.3
F	0.048	< 0.047	< 0.60	0.048 TO 0.65	0.0023 TO 0.032	20.	1.6
B	0.050	1.5	0.084	1.6	0.079	4.2	0.34
BE	0.0031	0.018	< 0.0005	0.021	0.0010	0.18	0.015
LI	0.0007	0.070	< 0.0068	0.070	0.0034	1.4	0.12

MC INDICATES A MAJOR COMPONENT OF THE SAMPLE.

- INDICATES THAT THE TOTAL AND EMISSION VALUES WERE NOT CALCULATED OWING TO THE PRESENCE OF AN MC CONCENTRATION.

** INDICATES A VALUE EXCEEDING ONE GRAM.

BITUMINOUS, PULVERIZED DRY BOTTOM

SITE 321: BITUMINOUS PULVERIZED DRY BOTTOM

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	XAD RESIN (MG)	COMP SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.68	< 1.8	< 0.050	< 0.0094	< 2.6	< 0.087	< 0.99	< 0.058
TH	< 1.9	< 1.8	< 0.073	< 0.014	< 3.8	< 0.13	< 1.4	< 0.084
BI	< 0.14	< 0.39	< 0.023	< 0.0042	< 0.55	< 0.019	< 0.45	< 0.026
PB	4.3	15.	< 0.55	0.020	19.	0.65	2.6	0.15
TL	< 0.83	< 0.24	< 0.028	< 0.0053	< 1.1	< 0.037	< 0.56	< 0.032
AU	< 0.036	< 0.29	< 0.038	< 0.0070	< 0.37	< 0.012	< 0.74	< 0.043
IR	< 0.056	< 0.44	< 0.058	< 0.011	< 0.57	< 0.019	< 1.1	< 0.067
OS	< 0.061	< 0.48	< 0.063	< 0.012	< 0.62	< 0.021	< 1.2	< 0.072
RE	< 0.18	< 0.30	< 0.040	< 0.0074	< 0.53	< 0.018	< 0.79	< 0.046
W	< 0.072	< 0.40	< 0.053	0.041	0.041 TO 0.53	0.0014 TO 0.018	< 4.2	< 0.25
HF	< 0.65	< 1.0	< 0.066	< 0.012	< 1.7	< 0.059	< 1.3	< 0.077
LU	< 0.26	< 0.69	< 0.016	< 0.0029	< 0.97	< 0.033	< 0.31	< 0.018
YB	< 0.19	< 0.18	< 0.023	< 0.0042	< 0.40	< 0.013	< 0.45	< 0.026
TM	0.055	< 0.11	< 0.014	< 0.0026	0.055 TO 0.12	0.0019 TO 0.0041	< 0.27	< 0.016
ER	0.34	< 0.31	< 0.041	< 0.0076	0.34	0.011	< 0.80	< 0.047
HO	0.075	< 0.29	< 0.013	< 0.0025	0.075 TO 0.30	0.0025 TO 0.0100	< 0.26	< 0.015
DY	0.37	< 2.3	< 0.023	< 0.0044	0.37 TO 2.4	0.013 TO 0.080	< 0.46	< 0.027
TB	< 0.0044	< 0.034	< 0.0063	< 0.0012	< 0.046	< 0.0016	< 0.12	< 0.0073
GD	< 0.41	< 0.71	< 0.023	< 0.0043	< 1.1	< 0.039	< 0.46	< 0.027
EU	0.14	0.19	< 0.0100	< 0.0020	0.33	0.011	< 0.21	< 0.012
SM	0.55	2.0	< 0.040	< 0.0076	2.5	0.086	< 0.80	< 0.047
ND	2.5	4.7	< 0.050	< 0.0094	7.3	0.25	< 1.0	< 0.058
PR	0.55	1.6	< 0.0089	< 0.0017	2.1	0.073	0.25	0.014
CE	8.1	16.	< 0.012	< 0.0090	24.	0.82	0.98	0.057
LA	8.2	12.	< 0.013	< 0.0024	20.	0.68	1.1	0.062
BA	77.	150.	< 0.60	0.11	230.	7.7	17.	0.96
CS	0.25	0.75	< 0.0041	< 0.0006	1.0	0.034	0.12	0.0068
I	< 0.041	< 0.16	0.14	< 0.0065	0.14	0.0048	< 0.68	< 0.040
TE	< 0.097	< 0.21	< 0.029	< 0.0055	< 0.35	< 0.012	< 0.58	< 0.034
SB	0.23	2.4	< 0.020	0.0076	2.7	0.091	< 0.40	< 0.023
SN	0.37	1.5	< 0.029	0.17	2.0	0.067	1.1	0.063
CD	0.053	0.23	< 0.036	0.0098	0.29	0.0099	0.70	0.041
PU	< 0.11	< 0.30	< 0.029	0.015	0.015 TO 0.43	0.0005 TO 0.015	< 0.57	< 0.033
RH	< 0.0098	< 0.077	< 0.0100	< 0.0019	< 0.099	< 0.0034	< 1.1	< 0.065

SITE 321: BITUMINOUS PULVERIZED DRY BOTTOM

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	XAD RESIN (MG)	COMP SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.030	< 0.24	< 0.037	< 0.0070	< 0.31	< 0.011	< 0.74	< 0.043
MO	0.15	1.5	0.17	3.2	5.1	0.17	0.96	0.056
NB	2.4	2.6	< 0.0043	0.0047	5.0	0.17	0.17	0.0100
ZR	17.	24.	< 0.016	< 0.0030	41.	1.4	1.3	0.077
Y	9.9	9.8	< 0.0067	0.0025	20.	0.67	0.77	0.045
SR	94.	130.	0.19	0.052	230.	7.7	14.	0.84
RB	5.7	27.	< 0.024	0.0044	33.	1.1	1.3	0.078
BR	0.51	< 3.8	0.21	0.038	0.76 TO 3.8	0.026 TO 0.13	2.7	0.16
SE	< 1.3	1.8	< 0.25	0.14	2.0	0.067	2.3	0.13
AS	6.1	96.	< 0.064	0.068	100.	3.5	9.8	0.57
GE	< 2.7	< 11.	< 0.014	< 0.0100	< 14.	< 0.46	< 1.1	< 0.064
GA	2.9	< 32.	< 0.0057	0.0087	2.9 TO 32.	0.097 TO 1.1	1.0	0.059
ZN	13.	81.	< 2.2	< 0.81	94.	3.2	16.	0.91
CU	8.8	25.	< 4.2	0.15	34.	1.1	12.	0.72
NI	11.	45.	< 3.0	0.76	57.	1.9	5.1	0.30
CU	7.6	15.	< 0.046	0.35	23.	0.78	0.56	0.033
FE	**	MC	< 6.4	73.	-	-	270.	16.
MN	11.	50.	< 0.22	1.8	63.	2.1	1.4	0.082
CR	4.0	11.	0.61	28.	43.	1.5	2.3	0.14
V	17.	57.	< 0.22	0.076	74.	2.5	3.8	0.22
TI	350.	920.	< 0.35	0.053	**	43.	2.4	0.14
CA	680.	**	3.9	0.79	**	74.	110.	6.5
K	**	MC	< 3.6	0.98	-	-	330.	19.
CL	< 19.	< 73.	< 10.	< 0.51	<100.	< 3.5	< 88.	< 5.2
S	490.	**	< 60.	360.	**	110.	1.4 (%)	800.
P	240.	**	< 1.6	< 0.83	**	73.	150.	8.5
SI	**	MC	1.8	11.	-	-	0.13 (%)	78.
AL	MC	MC	< 3.2	0.86	-	-	0.100 (%)	59.
MG	290.	**	< 1.5	11.	**	76.	63.	3.7
NA	80.	**	< 3.7	< 1.3	**	37.	130.	7.4
F	31.	140.	0.47	< 0.076	170.	5.9	80.	4.7
B	20.	160.	0.027	0.21	180.	6.1	< 6.1	< 0.36
BE	0.46	6.6	< 0.0041	< 0.0003	7.0	0.24	0.36	0.021
LI	7.1	56.	< 0.0064	< 0.0017	63.	2.1	1.3	0.076

MC INDICATES A MAJOR COMPONENT OF THE SAMPLE.

- INDICATES THAT THE TOTAL AND EMISSION VALUES WERE NOT CALCULATED OWING TO THE PRESENCE OF AN MC CONCENTRATION.

** INDICATES A VALUE EXCEEDING ONE GRAM.

SITE 343: BITUMINOUS, PULVERIZED DRY BOTTOM

ELEMENT	PR SOLIDS (MG)	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSI CALCULA (MG/DS
U	0.0027	0.0014	0.024	< 0.018	0.028	0.0014	< 0.40	< 0.035
TH	0.0038	0.0040	0.0046	< 0.026	0.012 TO 0.026	0.0006 TO 0.0013	< 0.58	< 0.050
BI	0.0004	0.0005	0.0053	< 0.0082	0.0062	0.0003	< 0.18	< 0.016
PB	0.12	0.062	0.088	< 0.14	0.27	0.014	1.7	0.15
TL	0.0012	0.0025	0.032	< 0.0100	0.035	0.0018	< 0.22	< 0.020
AU	< 0.0002	< 0.0002	< 0.0006	< 0.014	< 0.015	< 0.0007	< 0.30	< 0.026
IR	< 0.0002	< 0.0003	< 0.0009	< 0.021	< 0.022	< 0.0011	< 0.46	< 0.040
OS	< 0.0003	< 0.0003	< 0.0010	< 0.023	< 0.024	< 0.0012	< 0.50	< 0.044
RE	0.0003	< 0.0002	< 0.0006	< 0.014	0.0003 TO 0.015	< 0.0001 TO 0.0008	< 0.32	< 0.028
W	0.0005	0.0005	0.0018	< 0.019	0.0028 TO 0.019	0.0001 TO 0.0010	< 0.43	< 0.037
HF	0.0010	< 0.0006	< 0.0010	< 0.024	0.0010 TO 0.026	< 0.0001 TO 0.0013	< 0.53	< 0.046
LU	0.0001	< 0.0001	< 0.0002	< 0.0057	0.0001 TO 0.0060	< 0.0001 TO 0.0003	< 0.12	< 0.011
YB	0.0004	0.0004	0.0004	< 0.0082	0.0012 TO 0.0082	< 0.0001 TO 0.0004	< 0.18	< 0.016
TM	< 0.0001	< 0.0001	0.0001	< 0.0050	0.0003 TO 0.0050	< 0.0001 TO 0.0002	< 0.11	< 0.0096
ER	0.0005	0.0004	0.0009	< 0.015	0.0018 TO 0.015	< 0.0001 TO 0.0007	0.23	0.020
HO	0.0001	0.0001	0.0004	< 0.0049	0.0006 TO 0.0049	< 0.0001 TO 0.0002	< 0.11	< 0.0093
DY	0.0012	0.0009	0.0051	< 0.0085	0.0072	0.0004	0.27	0.024
TB	0.0001	< 0.0001	0.0014	< 0.0023	0.0016	< 0.0001	0.050	0.0044
GD	0.0012	0.0006	0.0006	< 0.0084	0.0024 TO 0.0084	0.0001 TO 0.0004	0.13	0.011
EU	0.0001	0.0006	0.0006	< 0.0038	0.0013 TO 0.0038	< 0.0001 TO 0.0002	< 0.084	< 0.0073
SM	0.0016	0.0031	0.0022	< 0.015	0.0069 TO 0.015	0.0003 TO 0.0007	0.32	0.028
ND	0.0050	0.0075	0.0075	< 0.018	0.020	0.0010	0.92	0.080
PR	0.0011	0.0024	0.0021	< 0.0032	0.0056	0.0003	0.14	0.012
CE	0.0061	0.013	0.023	< 0.0044	0.042	0.0021	0.72	0.063
LA	0.012	0.013	0.012	< 0.0047	0.038	0.0019	0.57	0.049
BA	0.30	0.64	2.5	< 0.052	3.4	0.17	27.	2.4
CS	0.0011	0.0047	0.0019	< 0.0008	0.0077	0.0004	0.25	0.022
I	< 0.0001	< 0.0041	< 0.0005	< 0.013	< 0.017	< 0.0009	< 0.55	< 0.048
TE	< 0.0001	< 0.0001	0.0010	< 0.011	0.0010 TO 0.011	< 0.0001 TO 0.0005	< 0.23	< 0.020
SB	0.0051	0.0054	0.019	< 0.0074	0.030	0.0015	0.16	0.014
SN	0.012	0.0065	0.053	< 0.63	0.072 TO 0.63	0.0036 TO 0.031	0.23	0.020
CD	0.0002	< 0.0001	0.0073	< 0.061	0.0076 TO 0.061	0.0004 TO 0.0030	0.64	0.056
PD	0.0004	0.0003	0.0008	< 0.011	0.0015 TO 0.011	< 0.0001 TO 0.0005	< 0.23	< 0.020

SITE 343: BITUMINOUS, PULVERIZED DRY BOTTOM

ELEMENT	PR SOLIDS (MG)	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSI CALCULA (MG/DS
RU	< 0.0001	0.0001	0.0006	< 0.014	0.0007 TO 0.014	< 0.0001 TO 0.0007	< 0.30	< 0.026
MO	0.012	0.0065	0.041	1.9	1.9	0.097	0.34	0.030
NB	0.0073	0.0078	0.0010	0.0032	0.019	0.0010	0.069	0.0060
ZR	0.036	0.053	0.015	0.0085	0.11	0.0056	0.91	0.079
Y	0.015	0.016	0.025	< 0.0024	0.056	0.0028	0.56	0.049
SR	0.14	0.30	1.0	< 0.024	1.5	0.074	16.	1.4
RB	0.015	0.045	0.021	< 0.0059	0.082	0.0041	1.9	0.17
BR	0.0100	0.099	0.098	< 0.075	0.21	0.0100	< 0.40	< 0.034
SE	0.021	0.13	1.0	0.030	1.2	0.059	2.5	0.22
AS	0.038	0.16	0.98	0.021	1.2	0.060	2.7	0.23
GE	0.0061	0.018	0.031	< 0.0051	0.055	0.0027	0.29	0.025
GA	0.012	0.098	0.089	0.0010	0.20	0.0099	0.68	0.059
ZN	0.042	0.045	0.93	0.42	1.4	0.071	2.3	0.20
CU	0.048	0.051	0.19	0.37	0.66	0.033	4.1	0.35
NI	0.58	0.31	0.27	6.2	7.3	0.36	1.3	0.12
CO	0.012	0.025	0.022	0.057	0.12	0.0058	0.23	0.020
FE	8.1	12.	6.0	9.1	35.	1.6	180.	16.
MN	0.034	0.051	0.073	0.42	0.58	0.029	1.1	0.096
CR	0.14	0.29	0.30	3.4	4.2	0.21	4.6	0.40
V	0.070	0.100	0.30	0.0088	0.48	0.024	2.3	0.20
TI	0.87	1.8	0.87	0.028	3.6	0.18	27.	2.3
SC	0.0046	0.0100	0.0074	< 0.0007	0.022	0.0011	0.24	0.020
CA	2.1	3.1	7.9	1.8	15.	0.74	360.	31.
K	3.9	2.9	4.4	< 3.0	11.	0.56	230.	20.
S	1.4	6.1	30.	98.	140.	6.7	0.54 (%)	470.
P	0.11	0.21	3.0	< 0.77	3.3	0.17	13.	1.1
SI	52.	21.	0.77	33.	110.	5.3	780.	68.
AL	18.	29.	14.	< 0.99	61.	3.0	480.	42.
MG	0.20	0.39	1.6	0.46	2.7	0.13	52.	4.5
NA	0.56	0.23	MC	7.9	-	-	49.	4.3
F	0.27	0.28	0.0075	< 0.13	0.56	0.028	15.	1.3
B	0.033	0.069	2.0	0.017	2.2	0.11	2.2	0.19
BE	0.0010	0.0031	0.018	< 0.0006	0.022	0.0011	0.098	0.0086
LI	0.0050	0.0009	0.017	0.0007	0.024	0.0012	1.5	0.13

MC INDICATES A MAJOR COMPONENT OF THE SAMPLE.

- INDICATES THAT THE TOTAL AND EMISSION VALUES WERE NOT CALCULATED OWING TO THE PRESENCE OF AN MC CONCENTRATION.

WOOD STOKER

SITE 219: WOOD-FIRED STOKER

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0008	< 0.0064	< 0.047	< 0.055	< 0.0023	< 0.38	< 0.033
TH	< 0.0011	< 0.0093	< 0.069	< 0.079	< 0.0033	< 0.56	< 0.047
BI	< 0.0005	< 0.0029	< 0.021	< 0.025	< 0.0010	< 0.17	< 0.015
PB	0.019	0.36	< 0.044	0.38	0.016	1.9	0.17
TL	< 0.0006	< 0.0036	< 0.027	< 0.031	< 0.0013	< 0.22	< 0.018
AU	< 0.0007	< 0.0048	< 0.035	< 0.041	< 0.0017	< 0.29	< 0.024
IR	< 0.0011	< 0.0074	< 0.055	< 0.063	< 0.0026	< 0.44	< 0.038
OS	< 0.0012	< 0.0081	< 0.059	< 0.068	< 0.0029	< 0.48	< 0.041
RE	< 0.0007	< 0.0051	< 0.038	< 0.043	< 0.0018	< 0.30	< 0.026
W	< 0.0005	< 0.0068	< 0.050	< 0.058	< 0.0024	< 0.41	< 0.035
HF	< 0.0025	< 0.0085	< 0.063	< 0.074	< 0.0031	< 0.51	< 0.043
LU	< 0.0006	< 0.0020	< 0.015	< 0.017	< 0.0007	< 0.12	< 0.0100
YB	< 0.0004	< 0.0029	< 0.021	< 0.025	< 0.0010	< 0.17	< 0.015
TM	< 0.0003	< 0.0018	< 0.013	< 0.015	< 0.0006	< 0.11	< 0.0090
ER	< 0.0008	< 0.0052	< 0.038	< 0.044	< 0.0019	< 0.31	< 0.026
HO	< 0.0001	< 0.0017	< 0.013	< 0.014	< 0.0006	< 0.100	< 0.0087
DY	0.0002	< 0.0030	< 0.022	0.0002 TO 0.025	< 0.0001 TO 0.0010	< 0.18	< 0.015
TB	< 0.0001	< 0.0008	< 0.0060	< 0.0001 TO 0.0066	< 0.0001 TO 0.0003	< 0.048	< 0.0041
GD	< 0.0004	< 0.0030	< 0.022	< 0.025	< 0.0011	< 0.18	< 0.015
EU	< 0.0003	< 0.0013	< 0.0099	< 0.012	< 0.0005	< 0.080	< 0.0066
SM	< 0.0009	< 0.0052	< 0.038	< 0.044	< 0.0019	< 0.31	< 0.026
ND	0.0007	< 0.0065	< 0.048	0.0007 TO 0.054	< 0.0001 TO 0.0023	< 0.39	< 0.033
PR	0.0003	< 0.0011	< 0.0084	0.0003 TO 0.0096	< 0.0001 TO 0.0004	< 0.068	< 0.0058
CE	0.0034	0.0008	< 0.011	0.0042 TO 0.011	0.0002 TO 0.0005	0.37	0.031
LA	0.0068	< 0.0017	< 0.012	0.0068 TO 0.014	0.0003 TO 0.0006	0.20	0.017
BA	0.17	0.18	0.070	0.42	0.018	26.	2.2
CS	< 0.0001	0.0020	< 0.0020	0.0021	< 0.0001	0.0080	0.0007
I	< 0.0008	0.018	< 0.033	0.018	0.0007	0.53	0.045
TE	< 0.0005	< 0.0037	< 0.028	< 0.032	< 0.0013	< 0.22	< 0.019
SB	0.0008	0.0100	< 0.019	0.011	0.0005	< 0.16	< 0.013
SN	0.0004	0.21	< 0.027	0.21	0.0088	0.59	0.051
CD	0.0008	0.0100	< 0.034	0.011 TO 0.034	0.0005 TO 0.0014	< 0.28	< 0.023
PD	< 0.0007	< 0.0037	< 0.027	< 0.032	< 0.0013	< 0.22	< 0.019
RH	< 0.0002	< 0.0013	< 0.0095	< 0.011	< 0.0005	< 0.077	< 0.0066

SITE 219: WOOD-FIRED STOKER

ELEMENT	10+3UM CYCLONE (MG)	PF+1UM CYCLONE (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0006	< 0.0048	< 0.035	< 0.041	< 0.0017	< 0.29	< 0.024
MO	0.0049	0.083	< 0.033	0.088	0.0037	< 0.26	< 0.022
NB	0.0005	< 0.0006	< 0.0041	0.0005 TO 0.0047	< 0.0001 TO 0.0002	< 0.033	< 0.0028
ZR	0.0049	0.0100	< 0.015	0.015	0.0006	0.54	0.046
Y	0.0041	0.0009	< 0.0063	0.0050	0.0002	0.100	0.0087
SR	0.16	0.064	0.020	0.24	0.0100	15.	1.3
RB	0.0057	0.13	0.0077	0.14	0.0059	1.9	0.16
BR	0.011	0.027	0.023	0.061	0.0026	0.79	0.067
SE	0.0031	0.011	< 0.019	0.014	0.0006	< 0.15	< 0.013
AS	0.0100	0.029	< 0.0073	0.039	0.0016	0.12	0.0100
GE	0.0024	0.0036	< 0.013	0.0060 TO 0.013	0.0002 TO 0.0005	< 0.11	< 0.0091
GA	0.0008	0.0055	< 0.0053	0.0062	0.0003	< 0.043	< 0.0037
ZN	0.090	1.4	0.14	1.6	0.068	2.7	0.23
CU	0.013	0.100	0.044	0.16	0.0066	3.0	0.25
NI	0.039	0.039	0.072	0.15	0.0063	2.1	0.18
CO	0.0032	0.0019	0.039	0.044	0.0019	0.12	0.0099
FE	3.2	1.1	4.2	8.5	0.36	91.	7.8
MN	0.43	0.15	0.032	0.61	0.025	18.	1.5
CR	0.018	0.040	0.100	0.16	0.0069	1.5	0.13
V	0.0047	0.0022	< 0.0022	0.0069	0.0003	< 0.018	< 0.0015
TI	0.17	0.070	0.025	0.26	0.011	13.	1.1
CA	23.	2.0	1.9	27.	1.1	0.15 (%)	130.
K	1.9	61.	0.13	63.	2.6	440.	37.
S	3.2	87.	1.8	92.	3.9	100.	8.7
P	0.89	4.8	0.059	5.7	0.24	24.	2.0
SI	3.7	2.2	36.	42.	1.8	580.	50.
AL	0.47	0.52	0.30	1.3	0.054	40.	3.4
MG	1.2	< 2.4	0.47	1.7	0.072	260.	22.
NA	0.11	< 18.	0.88	1.0 TO 18.	0.042 TO 0.77	15.	1.2
F	0.30	0.32	< 0.34	0.62	0.026	< 11.	< 0.95
B	0.29	0.18	0.046	0.62	0.022	0.072	0.0061
BE	0.0011	0.0003	< 0.0006	0.0014	< 0.0001	< 0.0022	< 0.0002
LI	0.0079	0.012	0.021	0.040	0.0017	0.084	0.0071

INTERNAL COMBUSTION
OIL-FIRED RECIPROCATING ENGINES

ELEMENT	SITE 329: IC OIL-FIRED ENGINE		SITE 347: IC ENGINE		SITE 348: IC ENGINE		SITE 350: IC ENGINE	
	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.14	< 0.0048	< 0.15	< 0.0014	< 0.15	< 0.0027	< 0.075	< 0.0026
MO	< 0.13	< 0.0044	< 0.14	< 0.0013	< 0.13	< 0.0025	0.035	0.0012
NB	< 0.017	< 0.0005	< 0.017	< 0.0002	< 0.017	< 0.0003	0.0044	0.0001
ZR	< 0.063	< 0.0021	< 0.064	< 0.0006	< 0.064	< 0.0012	< 0.033	< 0.0011
Y	< 0.026	< 0.0008	< 0.026	< 0.0002	< 0.026	< 0.0005	< 0.013	< 0.0005
SR	0.13	0.0043	0.071	0.0007	0.11	0.0020	0.025	0.0008
RB	0.022	0.0007	0.0080	< 0.0001	0.0079	0.0001	0.0041	0.0001
BR	0.20	0.0066	< 0.58	< 0.0055	< 0.40	< 0.0074	< 0.42	< 0.014
SE	< 0.15	< 0.0051	< 0.078	< 0.0007	< 0.077	< 0.0014	0.084	0.0029
AS	0.060	0.0020	< 0.031	< 0.0003	< 0.030	< 0.0005	0.016	0.0005
GE	< 0.054	< 0.0018	< 0.055	< 0.0005	< 0.054	< 0.0010	< 0.028	< 0.0010
GA	< 0.044	< 0.0014	< 0.022	< 0.0002	< 0.022	< 0.0004	< 0.011	< 0.0004
ZN	1.7	0.057	2.3	0.022	2.3	0.042	2.3	0.080
CU	6.4	0.21	24.	0.23	5.7	0.100	6.1	0.21
NI	< 2.8	< 0.092	2.8	0.026	0.61	0.011	0.63	0.022
CO	0.031	0.0010	0.022	0.0002	0.022	0.0004	0.022	0.0008
FE	< 7.8	< 0.26	3.7	0.035	1.4	0.025	8.4	0.29
MN	0.27	0.0091	0.18	0.0017	0.11	0.0021	0.12	0.0041
CR	0.28	0.0092	0.54	0.0051	0.25	0.0046	0.26	0.0090
V	0.20	0.0065	0.28	0.0026	0.14	0.0025	0.14	0.0049
TI	0.16	0.0053	0.20	0.0019	0.29	0.0053	0.060	0.0021
SC	-	-	0.058	0.0005	0.058	0.0011	0.059	0.0021
CA	5.2	0.17	8.7	0.082	5.5	0.100	3.6	0.13
K	18.	0.59	8.0	0.076	1.8	0.033	1.9	0.064
S	410.	14.	230.	2.2	470.	8.5	160.	5.7
P	< 1.1	< 0.035	0.62	0.0059	1.4	0.025	0.41	0.014
SI	< 6.3	< 0.21	130.	1.2	20.	0.36	37.	1.3
AL	13.	0.43	< 5.4	< 0.051	< 2.7	< 0.049	< 3.9	< 0.14
MG	< 4.0	< 0.13	1.2	0.011	1.8	0.033	0.74	0.025
NA	< 23.	< 0.77	4.3	0.041	6.9	0.13	2.8	0.097
F	< 0.38	< 0.012	< 0.72	< 0.0068	< 0.19	< 0.0035	< 0.20	< 0.0068
B	0.072	0.0024	0.13	0.0012	0.030	0.0005	< 0.014	< 0.0005
BE	< 0.0011	< 0.0001	< 0.0020	< 0.0001	< 0.0020	< 0.0001	< 0.0020	< 0.0001
LI	< 0.022	< 0.0007	0.011	0.0001	0.022	0.0004	0.0083	0.0003

APPENDIX D

METRIC CONVERSION FACTORS AND PREFIXES

CONVERSION FACTORS

To convert from	To	Multiply by
Degrees Celsius (°C)	Degrees Fahrenheit (°F)	$t(°F) = 1.8\ t(°C) + 32$
Joule (J)	Btu	9.478×10^{-4}
Kilogram (kg)	Pound-mass (avoirdupois)	2.205
Kilojoule/kilogram (kJ/kg)	Btu/lb_m	4.299×10^{-1}
Megagram (Mg)	Ton (2000 lb_m)	1.102
Megawatt (MW)	Horsepower (HP)	1.341×10^{3}
Meter (m)	Foot (ft)	3.281
Meter^3 (m^3)	Barrel (bbl)	6.290
Meter^3 (m^3)	Foot^3 (ft^3)	3.531×10^{1}
Meter^3 (m^3)	Gallon (gal)	2.642×10^{2}
Nanogram/joule (ng/J)	lb_m/million Btu	2.326×10^{-3}
Picogram/joule (pg/J)	lb_m/million Btu	2.326×10^{-6}

PREFIXES

Prefix	Symbol	Multiplication Factor	Example
Peta	P	10^{15}	1 Pm = 1×10^{15} meters
Tera	T	10^{12}	1 Tm = 1×10^{12} meters
Giga	G	10^{9}	1 Gm = 1×10^{9} meters
Mega	M	10^{6}	1 Mm = 1×10^{6} meters
Kilo	k	10^{3}	1 km = 1×10^{3} meters
Milli	m	10^{-3}	1 mm = 1×10^{-3} meter
Micro	μ	10^{-6}	1 μm = 1×10^{-6} meter
Nano	n	10^{-9}	1 nm = 1×10^{-9} meter
Pico	p	10^{-12}	1 pm = 1×10^{-12} meter