EPA-600/7-79-029b
May 1979

②

FUEL OIL
COMBUSTION
AP-42 Section 1.
Reference Number

EPA

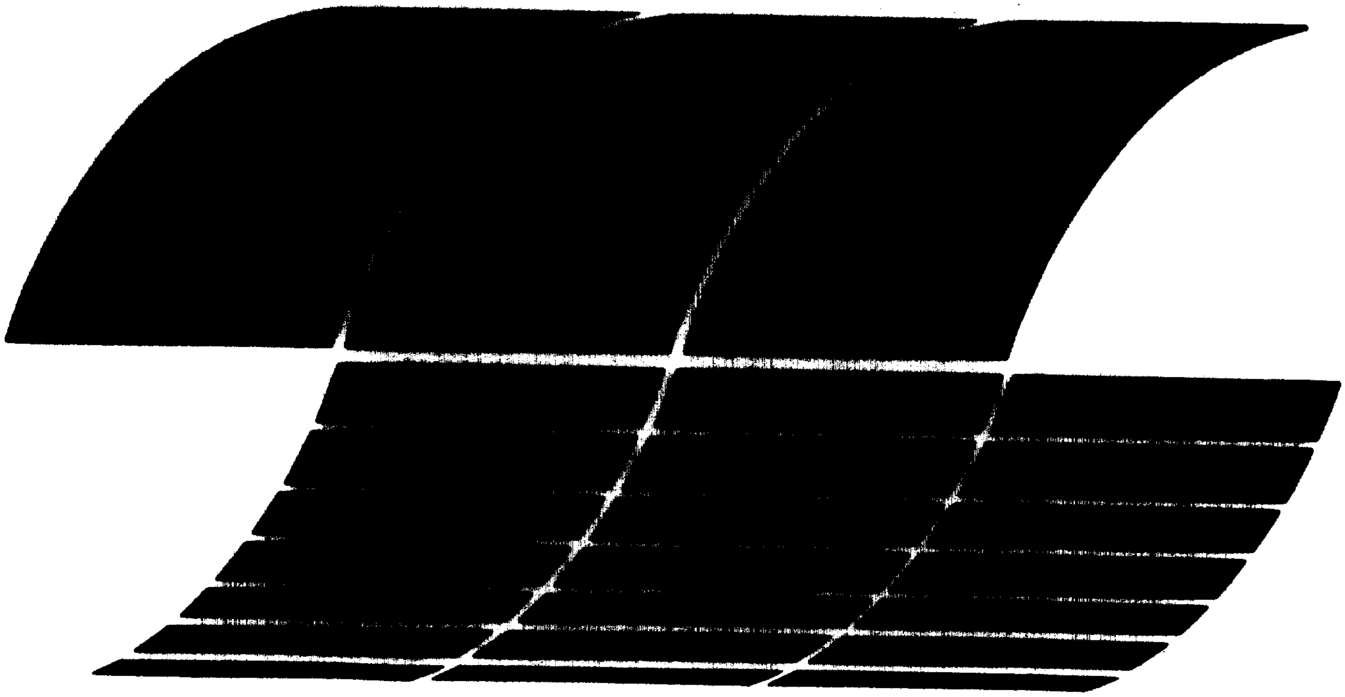
8/82

Ref 15 Sec 1.3
Supp 13
8/82

Emissions Assessment of Conventional Stationary Combustion Systems;
Volume I. Gas- and and Oil-fired Residential Heating Sources

FYI
There are some discussion on filtered addl vs total for gas and oil sources in each part of this report.

Interagency Energy/Environment R&D Program Report



RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

EPA REVIEW NOTICE

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

Section 1.3 Reference no. 17

EPA-600/7-79-029b

May 1979

Emissions Assessment of Conventional Stationary Combustion Systems;

Volume I. Gas- and Oil-fired Residential Heating Sources

by

N. F. Surprenant, R. R. Hall, K. T. McGregor,
and A. S. Werner (GCA Technology Division)

TRW, Inc.
One Space Park
Redondo Beach, California 90278

Contract No. 68-02-2197
Program Element No. EHE624A

EPA Project Officer: Ronald A. Venezia

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

1

0

ABSTRACT

Emissions from gas- and oil-fired residential heating sources were assessed through a critical examination of existing emissions data, followed by the conduct of a phased measurement program to fill gaps in the emissions data base. Initially, five gas-fired and five oil-fired residential sources were selected for testing. Mass emission rates of criteria pollutants, trace elements, and organics, including polycyclic organic matter (POM), were determined. Subsequent evaluation of the test program led to a decision to conduct additional tests at one gas-fired and two oil-fired sites. The principal objective of this second test program was to determine the effect of burner on/off cycle on emissions. Particulate sulfate, SO_2, and SO_3 emission data were also obtained at the oil-fired sites.

The results of the emissions assessment indicate that residential sources are of potential significance based on multiple source severity factors calculated for an array of houses burning gas or oil. Pollutants for which multiple source severity factors exceed 0.05, the level which may be potentially significant, are NO_x from gas-fired sources and SO_3, NO_x, and Ni from oil-fired sources. Measured criteria pollutant emission factors were generally comparable to EPA emission factors given in AP-42 with the exception of total hydrocarbon emissions from oil-fired sources which were three times greater. However, POM compounds known to be carcinogenic were not found above the detection limit of 0.3 μg/m^3. In contrast to previous studies, variations in the burner operating cycle had no measurable effect on emissions. Failure to detect an effect may be due to the accuracy limitation (± a factor of three) inherent in Level I measurements.

CONTENTS

CONTENTS (continued)

Appendices

FIGURES

TABLES

TABLES (continued)

TABLES (continued)

TABLES (continued)

ACKNOWLEDGMENT

The authors gratefully acknowledge the technical guidance of the following individuals who contributed to the review and revision of this report: Ronald A. Venezia, Project Officer; Edward G. Bobalek; Robert E. Hall; William B. Kuykendal; Warren Peters; Wade H. Ponder; Kenneth E. Rowe; and W. Gene Tucker of the Industrial Environmental Research Laboratory (IERL), Research Triangle Park, North Carolina; Don Gilmore, Environmental Monitoring and Support Laboratory, Las Vegas, Nevada; Victor F. Jelen, IERL, Cincinnati, Ohio; and Robert G. Hooper of the Electric Power Research Institute. The authors further acknowledge the contribution of the GCA and TRW field and laboratory personnel who were responsible for sample collection and analysis. A special acknowledgment is extended to Sandra M. Sandberg who played a major role in the technical preparation and editing of this document.

1. SUMMARY AND CONCLUSIONS

Emissions from gas- and oil-fired residential combustion sources for space heating have been assessed through a review and evaluation of the existing emissions data base in conjunction with a phased sampling and analysis measurement program designed to fill data gaps. Similar assessments of emissions from electricity generation and industrial internal combustion sources, electricity generation external combustion sources, industrial external combustion sources and commercial/institutional external combustion sources are being conducted and results will be presented in future reports.

This phased approach to an emissions assessment is designed to provide comprehensive information in a cost-effective manner through two distinct sampling and analysis levels. Level I procedures[1] utilize semiquantitative (± a factor of three) techniques of sample collection and laboratory and field analyses: (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 which 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. A third phase, Level III, which is outside the scope of this program, employs continuous or periodic monitoring of specific pollutants identified at Level II so that the emission rates of these critical components can be determined exactly as a function of time and operating condition.

1.1 RESIDENTIAL SOURCE DESCRIPTION

Residential space heating sources are defined as combustion units with fuel input capacities below 422×10^6 joules per hour (0.4×10^6 Btu/hr)* in accordance with recent U.S. Environmental Protection Agency (EPA) sponsored studies. Residential combustion systems consume about 15 percent of the fuel used by conventional stationary combustion systems. The residential sector accounts for about 6.8×10^{18} joules of the 1978 estimated fuel consumption total of 45×10^{18} joules. This source uses primarily gas (58 percent) and oil (38 percent). It is estimated that in 1974 there were about 34,000,000 gas-fired, 13,000,000 oil-fired, 740,000 coal-fired, and 660,000 wood-fired residential space heating systems in the United States.

Heating systems for residential 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 Pennsylvania, New York, New Jersey, Massachusetts, and Connecticut consuming 53 percent of the U.S. total. Only very small amounts of oil are burned in the west and south. Residential gas consumption for space heating is more widely distributed than oil, but is still most heavily concentrated in the upper midwest and northeast. States that account for more than 5 percent of the U.S. total residential gas consumption include Illinois (8.9 percent), New York (8.3 percent), Ohio (8.1 percent), California (7.8 percent), Michigan (7.6 percent), and Pennsylvania (6.0 percent).

Residential gas- and oil-fired space heating equipment is subject to a number of design variations related to burners, combustion chambers, excess air, heating medium, etc. Residential systems generally operate only in an on/off mode with no variation in fuel input rate in contrast to load modulation encountered with larger commercial, industrial, and electric utility systems.

Gas-fired systems are inherently less complex and easier to maintain than oil-fired units because the fuel is cleaner and atomization is not

---

*1 Btu = 1,055 joules (J). Although it is EPA policy to use the metric system, this publication uses certain nonmetric units for convenience. A conversion table is presented in Appendix A.

required. Residential gas burners use natural aspiration and are very similar in design, whereas several burner designs are used for oil atomization. However, high pressure (~100 psig) atomization burners account for about 90 percent of the total.[2] Low pressure and rotary burners are being phased out because of their complexity. Although air pollution control equipment is not available for residential combustion systems, emission reduction measures are being evaluated. The EPA is active in the development and evaluation of residential gas- and oil-fired burners and furnaces.

1.2 THE EXISTING RESIDENTIAL SOURCE EMISSIONS DATA BASE

A major task in this program has been the identification of gaps and inadequacies in the existing emissions data base for residential combustion sources. Decisions as to the adequacy of the data base were made using criteria developed by considering both the reliability and variability of the data. Environmental risks associated with the emission of each pollutant were also considered in the determination of the need for, and extent of, the phased sampling and analysis program.

The sources of emissions data for residential gas- and oil-fired systems are limited at the present time to early data used to generate EPA emission factors and more recent data developed by EPA contractors for criteria pollutants. For gas-fired systems, the existing data base for SO_2, NO_x, HC, and CO emissions is adequate. ~~However, the existing data base~~ for particulate and organic emissions is inadequate. For oil-fired systems, the existing emissions data base for particulate, SO_2, NO_x, HC, and CO is adequate, but inadequate for SO_3, particulate sulfate, trace element, and organic emissions.

1.3 THE RESIDENTIAL SOURCE MEASUREMENT PROGRAM

To remedy deficiencies in the existing emissions data base, five gas-fired and five oil-fired residential sources were initially selected for testing. The choice of specific sites within the two source categories was based on the representativeness of the sites with respect to such important system characteristics as burner type and age, firing rate, and heating medium (hot air, hot water, and steam). Upon review of the results obtained from the testing of the 10 sites, one gas-fired and two oil-fired systems were subsequently tested to study the effect of cycle mode on organic emissions. Level II analyses for SO_2, SO_3, and particulate sulfate were also conducted at the two oil-fired sites.

1.3.1 Field Testing

The Source Assessment Sampling System (SASS) train was used to collect both gas phase and particulate emissions in quantities sufficient for the wide range of analyses needed to adequately characterize residential source emissions. In addition to using the SASS train for stack gas sampling, other equipment was employed to collect those components not analyzable from the train samples. A gas chromatograph (GC) with flame ionization detection was used in the field to analyze low boiling hydrocarbons (boiling point $< 100^\circ C$). Additionally, CO, O_2, and CO_2 were field analyzed by GC using a thermal conductivity detector. Detection tubes were used for CO in the second series of tests to increase measurement sensitivity because the detection limits attainable for CO by the field GC were above CO levels normally measured in the stacks of residential heating systems. Analyses for NO_x were carried out at the gas-fired sites electrochemically using a Theta detector. NO_x emissions were not analyzed at the oil-fired sites. Goksöyr-Ross sampling and analysis for SO_2, SO_3, and particulate sulfate were also conducted at the two additional oil-fired sites tested later in the program.

1.3.2 Laboratory Analysis

The basic Level I sampling and analytical scheme for particulate and gaseous emissions is depicted in Figure 3 (Section 4). The analytical scheme was modified, however, for this emissions assessment program. The major modification of the Level I sampling and analysis procedure was that gas chromatography/mass spectroscopy (GC/MS) analyses for POM were performed on the samples collected in this program. Level II analyses for SO_2, SO_3, and particulate sulfate were also conducted for the two oil-fired sites tested in the second stage of the program.

1.3.2.1 Inorganic Analyses--

The Level I analysis scheme was used for all inorganic analyses. This scheme was designed to identify elemental species in the SASS train fractions and to provide semiquantitative data on elemental distributions and total emission factors. The primary tool for Level I analysis is the Spark Source

TABLE 19. FIELD DATA: GAS-FIRED RESIDENTIAL COMBUSTION SOURCES

Unit No.	Test No.	Cycle, on/off	Date of test	Rated input (10^6 J/hr)	CO_2 (%)	O_2 (%)	CO (ppmv)[*]	Particulate emissions		NO_x emissions		Bacharach smoke number
								(mg/m^3)	(ng/J)	(ppmv)[*]	(ng/J)	
1	100	50/10	6/10/77	85	6.4	16.7	ND	0.46	0.55	53	31	-
1	127[†]	-	3/13/78	85	9.3	9.7	1220	ND	ND	ND	ND	0-1
2	101	50/10	5/24/77	85	1.4	12.9	ND	0.40	0.26	11	6	-
2	128[†]	-	3/13/78	85	7.9	11.3	0	ND	ND	ND	ND	0-1
3	102	50/10	5/26/77	85	3.0	19.5	ND	0.49	1.7	119	66	-
3	125[†]	-	3/10/78	85	4.4	14.3	16	ND	ND	ND	ND	-
4	103	50/10	6/08/77	106	1.7	19.1	ND	0.64	1.7	66	33	-
4	126[†]	-	3/17/78	106	5.7	11.6	0	ND	ND	ND	ND	0-1
5	104	50/10	6/14/77	79	1.1	16.8	ND	0.62	0.76	21	11	-
6	129[†]	-	3/13/78	85	5.4	10.5	920	ND	ND	ND	ND	1
6	130	50/10	3/14/78	85	4.1	15.8	ND	ND	ND	ND	ND	-
6	131	10/20	3/15/78	85	3.5	14.3	ND	ND	ND	ND	ND	-

[*] ppmv values at 3 percent O_2.

[†] Parameter check at exit from heat exchanger; other tests at stack exit.

ND - Not Determined.

TABLE 1. SUMMARY OF RESULTS OF EMISSIONS ASSESSMENT FOR RESIDENTIAL SOURCES

Pollutant	Gas-fired sources				Oil-fired sources			
	Emissions from AP-42^3 (ng/J)	Emissions (ng/J)	Severity factor	Multiple source severity factor	Emissions from AP-42^3 (ng/J)	Emissions (ng/J)	Severity factor	Multiple source severity factor
Particulate	2 - 6	1.0	1.7×10^{-5}	4.3×10^{-4}	7.7	3.1	7.7×10^{-5}	1.9×10^{-3}
SO_2*	0.26	ND	3.2×10^{-6}	8.0×10^{-5}	106.	ND	1.9×10^{-3}	4.8×10^{-2}
SO_3	ND	ND	ND	ND	1.5	5.9	1.6×10^{-2}	4.0×10^{-1}
NO_x	33.	33.	2.8×10^{-3}	7.0×10^{-2}	55.	ND	6.2×10^{-3}	1.6×10^{-1}
CO	8.4	ND	1.6×10^{-6}	4.0×10^{-5}	15.	ND	4.2×10^{-6}	1.1×10^{-4}
Organics (total)	3.3	2.6	1.0×10^{-4}	2.5×10^{-3}	3.	9.2	5.3×10^{-4}	1.3×10^{-2}
Trace elements†								
Lead	-	-	-	-	-	7.5×10^{-2}	1.0×10^{-3}	17×10^{-3}
Cadmium	-	-	-	-	-	2.2×10^{-2}	1.0×10^{-3}	23×10^{-3}
Copper	-	-	-	-	-	0.25	2.4×10^{-3}	12×10^{-3}
Nickel	-	-	-	-	-	0.49	$10. \times 10^{-3}$	250×10^{-3}
Chromium	-	-	-	-	-	5.5×10^{-2}	1.0×10^{-3}	25×10^{-3}

*Based on fuel sulfur content of 2000 grains/10^6 ft^3 for gas and 0.25 weight percent for oil.

†Multiple source severity factors for all elements dashed (-) or not listed were less than 0.01. Upper bound values of emissions were used to calculate severity for oil-fired sources.

ND - Not Determined.

Severity factors calculated from program emission data or, in the case of pollutants not measured in the program, from EPA (AP-42)[3] emission factors are shown for a single source and for multiple sources. Maximum ground level concentrations for multiple sources were determined using a dispersion model for an array of 1000 sources. The model assumes a Class C stability (slightly unstable) and a windspeed of 4.5 m/sec (10 mph). Using a grid of houses 80 × 80 m and the average stack parameters found in this study, the maximum ground level concentrations determined by the model were about 25 times greater than those from a single source. As shown in Table 1, multiple source severity factors for several pollutants (NO_x for gas-fired sources and NO_x, SO_3, and Ni for oil-fired sources) exceed 0.05, a value which indicates that emissions are potentially significant.

Data for POM obtained by GC/MS are not reported in the table. POM was not found in the emissions from gas-fired residential sources; the concentrations of POM measured for oil-fired sources were at least two orders of magnitude below levels that are considered hazardous. Compounds considered particularly hazardous, such as benzo(a)pyrene and benzo(a)anthracene, were not detected.

In contrast with earlier studies, a change in the on/off cyclic mode of burner operation from a 50 minute on/10 minute off cycle to a 10 minute on/20 minute off cycle did not result in increased HC (or POM) emissions.

1.4 CONCLUSIONS

Several conclusions, as listed below, can be drawn from this emissions assessment of gas- and oil-fired residential sources.

- Multiple source severity factors determined for an array of 1000 residential sources exceed 0.05 for a number of pollutants. These pollutants, of potential environmental significance, are NO_x from gas-fired sources and NO_x, SO_3, and Ni from oil-fired sources.
- The average emission factors for criteria pollutants measured in this program, despite large source-to-source variations, are in agreement with EPA emission factors (AP-42) within the Level I accuracy of a factor of three.

A singular exception is the HC emission factor which is 3.1 times greater than the EPA emission factor. The multiple source severity factor for HC emissions from oil-fired sources is 1.3×10^{-2}. Emissions of criteria pollutants are adequately characterized.

- Particulate, SO_2, and NO_x emissions from residential sources account for about 0.4, 1.2, and 2.5 percent, respectively, of emissions from all stationary combustion sources based on a previous estimate of total nationwide emissions.[4] Residential CO emissions account for about 7 percent of the total CO emissions from stationary sources, with gas- and oil-fired sources contributing equally. HC emissions from residential sources account for about 10 percent of the total HC emissions from stationary combustion sources, with oil-fired sources contributing 62 percent of the gas- and oil-fired residential total.

- SO_3 emissions from oil-fired residential sources represent a potential hazard. The SO_3 emission factor measured in this program is three times greater than the EPA emission factor.[3] Further work is needed to determine SO_3 emission factors.

- Trace element emissions from gas-fired residential sources are insignificant. The only element emitted from oil-fired sources of potential environmental significance is Ni. The multiple source severity factor for Ni is 0.25.

- POM emissions, as measured in this program, are not environmentally significant. No POM emissions were detected from gas-fired sources. POM multiple source severity factors from oil-fired units are generally two to five orders of magnitude below levels considered hazardous. Although the data obtained in this study represent a valuable contribution to a sparse existing data base, further work is desirable because of the high level of potential hazard associated with POM.

- Within the accuracy limitations of Level I (± a factor of three), a change in burner cycle mode from 50 minutes on/10 minutes off to 10 minutes on/20 minutes off had no effect on HC and POM emissions. The effect of cycle on emissions noted by other investigators is undoubtedly a real effect and merits further study to determine its magnitude and significance.

On the basis of the above, further work is recommended to determine SO_3 concentrations and the effect of cycle variations on emissions from oil-fired sources. Additional work to determine emission factors for POM should be undertaken to build a larger data base. Modeling studies are also recommended to determine severities from a multiple array of oil-fired sources, using EPA emission factors and the trace element content of oil to provide emission rate data for the model. The emission data base for gas-fired residential sources is adequate and no further work is needed.

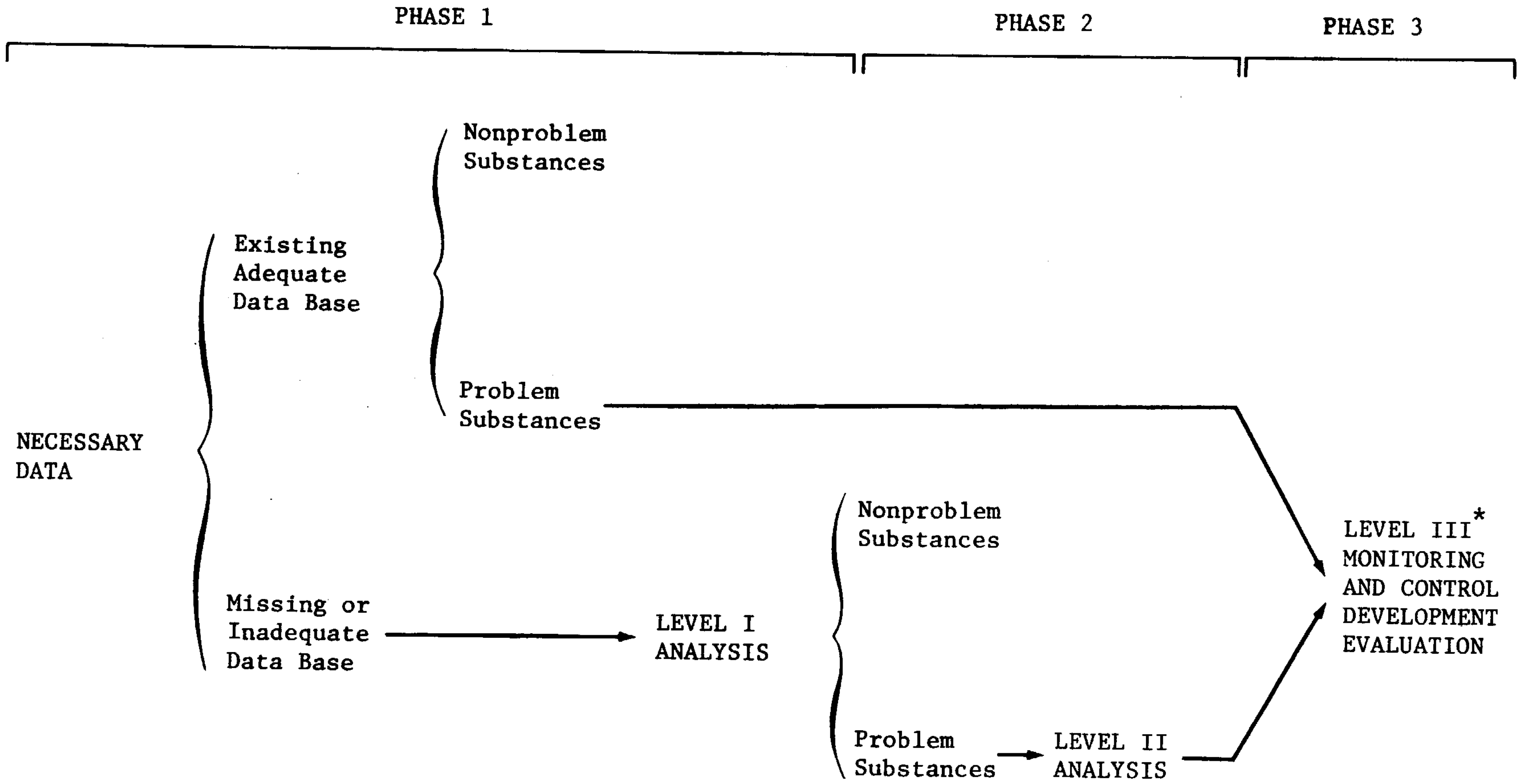
2. INTRODUCTION

Conventional stationary combustion systems are major sources of pollution of air, water, and land. A preliminary assessment[4] of the relative significance of stationary combustion systems as sources of pollution estimated that these combustion sources contribute a major portion of the total manmade emissions of nitrogen oxides, sulfur oxides, and particulates (Table 2). This preliminary assessment also identified as generally inadequate the emissions data for a number of potentially harmful pollutants, including trace elements, SO_3, and particulate sulfate.

TABLE 2. ESTIMATED CONTRIBUTION OF STATIONARY COMBUSTION SOURCES TO ANTHROPOGENIC AIR POLLUTANTS, 1973[4]

Pollutant	Emissions (10^3 tonnes/yr)	Percent of total manmade emissions
Particulates	6,420	20
SO_x	20,050	71
NO_x	10,000	44
HC	320	1
CO	980	1

The overall objective of the current program is to provide a comprehensive assessment of emissions from selected conventional stationary combustion systems. The assessment process is based on a critical examination of existing data, followed by a phased measurement approach to resolve data gaps (Figure 1). In the first phase, modified Level I sampling and analysis procedures are used to provide results accurate to a factor of three so that preliminary assessments can be made and problem areas identified. Evaluation of results from the first phase will determine pollutants requiring a more



*Not within the scope of the present program.

Figure 1. Program plan.

detailed and accurate Level II sampling and analysis program. The characterization of combustion source emissions from this program will allow EPA to determine the environmental acceptability of combustion waste streams and pollutant levels and the need for control of those pollutants which are environmentally unacceptable.

A third phase, Level III, which is outside the scope of this program, employs continuous or periodic monitoring of specific pollutants identified at Level II so that the emission rates of these critical components can be determined accurately as a function of time and operating condition.

The combustion source types to be assessed in this conventional combustion emissions assessment program have been selected because they are among the largest, potentially largest, or most numerous stationary combustion source types. A total of 50 source types have been selected for study and classified under the following principal categories:

1. Electricity generation - External combustion
2. Industrial - External combustion
3. Electricity generation and industrial - Internal combustion
4. Commercial/Institutional - Space heating
5. Residential - Space heating.

These five principal categories have been further divided into subcategories based on fuel type, furnace design, and firing method because their emission characteristics are dependent upon these parameters.

This program report is the first in a series of five reports, and is concerned with the emissions assessment of gas- and oil-fired residential combustion sources used for space heating (category 5, above). Residential coal and wood combustion sources are being studied under a separate EPA contract.

The approach utilized in the emissions assessment of residential combustion sources is similar to that utilized for the assessment of other combustion source types. First, available information concerning the process and population characteristics of residential combustion sources and their emissions was reviewed to determine the adequacy of the available data base.

Modified Level I sampling and analysis was then conducted at selected representative sites (initially five gas-fired and five oil-fired residential sites) to remedy inadequacies in the existing data base. The results of the modified Level I sampling and analysis program were then evaluated to determine the need for Level II or additional Level I sampling and analysis and to identify the potentially hazardous substances emitted from these combustion sources. As a result of this evaluation, a decision was made to acquire SO_2, SO_3, and particulate sulfate emission data and to study the effect of burner cycle mode on emissions. This additional testing and analysis have been conducted and results are included in this report. Lastly, emissions data obtained from the sampling and analysis programs were combined with existing emissions data to provide estimates of current and future nationwide emissions of pollutants from gas- and oil-fired residential combustion sources.

3. SOURCE DESCRIPTION

Residential combustion systems for space heating are classified as units with fuel input capacities below 422×10^6 J/hr (0.4×10^6 Btu/hr) in accordance with recent U.S. Environmental Protection Agency sponsored studies. The focus of this study is gas- and oil-fired residential heating systems. Gas and oil are the most important residential space heating fuels, representing 58 percent and 38 percent, respectively, of 1978 fuel consumption. Although these systems are not considered to be a major source of nationwide pollutant emissions,[4] their environmental impact is enhanced by high seasonal fuel consumption, winter meteorological conditions, proximity of the population to the emissions sources, and the release of emissions at close-to-ground level. To provide a better understanding of the emission problem associated with gas- and oil-fired home heating sources, and to aid in the selection of representative test units, brief descriptions of industry size and geographic distribution, population characteristics, and the design and operating characteristics of combustion equipment are discussed in this section.

3.1 SIZE OF INDUSTRY AND GEOGRAPHIC DISTRIBUTION

Residential combustion systems consume about $6{,}750 \times 10^{15}$ J/yr of fuel for space heating based on 1978 estimates presented in this report. Other conventional stationary combustion systems burn a total of $38{,}000 \times 10^{15}$ J/yr. Residential systems use primarily gas (58 percent) and oil (38 percent) in contrast to the electric utility sector which burns primarily coal (55 percent).

Pollutant mass emissions estimates developed in a previous study[4] indicated that gas- and oil-fired residential combustion sources account for roughly 2 percent of total particulates, 5 percent of SO_x, 3 percent of NO_x, 13 percent of HC, and 17 percent of CO emissions from the stationary combustion sources considered in this study.

Heating systems for residential sources are concentrated in areas of high population density. Regional residential space heating fuel consumption data for 1975 are presented in Table 3 and Figure 2. The distribution of fuel usage by region is probably very similar for the years 1975 and 1978. Data inputs used to develop Table 3 and Figure 2 include the number of dwelling units using each fuel and the average heating degree days in each state, typical heat requirements for an average dwelling unit, and Bureau of Mines fuel sales data. A complete discussion of the methodology used to develop Table 3 and Figure 2 can be found in Appendix B. An update of national fuel consumption values to 1978 has been made and is discussed in Section 5.

Table 3 and Figure 2 show that about 60 percent of residential fuel oil is burned in the northeast region. This region also contains 37 percent of the U.S. population.[5] Residential gas consumption (natural and LPG) for space heating is more widely distributed than oil, but is still most heavily concentrated in the upper midwest and the northeast. States that consume more than 5 percent of the U.S. total include Illinois (8.9 percent), New York (8.3 percent), Ohio (8.1 percent), California (7.8 percent), Michigan (7.6 percent), and Pennsylvania (6.0 percent).

In 1974 there were 70,831,000 occupied single and multiple dwelling units in the United States.[6] The majority of these dwelling units, 60,500,000, were heated by gas or oil. Single unit structures accounted for 50,000,000 units; multiple unit dwellings numbered another 4,000,000. Further analyses indicate that there were about 34,000,000 gas-fired and 13,000,000 oil-fired residential space heating systems in service in 1974. Similar analyses indicate that in 1974 about 740,000 coal-fired and 660,000 wood-fired residential units were in operation.

Although prediction of fuel use trends is subject to many uncertainties, consumption of gas and oil for residential space heating is expected to decrease 2.9 percent and increase 3.5 percent, respectively, from 1978 to 1985 (see Section 5). The prediction of future trends in the pattern of fuel use for residential space heating is difficult due to uncertainties in international oil production, distribution, and pricing; however, it would appear inevitable that reliance on oil must eventually diminish. Gas heating

TABLE 3. U.S. RESIDENTIAL SPACE HEATING FUEL USE BY REGION, 1975, 10^{15} J/yr[*]

Region	Gas		Oil[§]	Coal		Wood[§§]	All fuels
	Natural[†]	LPG[‡]		Anthracite[#]	Bituminous[**]		
United States	3,794	316	2,550	64.3	54.9	49.9	6,833
Northeast	801	23	1,515	50.8	0.2	4.6	2,395
New England	119	7	515	1.5	0.2	2.6	647
Middle Atlantic	681	16	999	49.4	0.0	2.1	1,748
North Central	1,686	150	593	9.6	23.0	7.9	2,468
East North Central	1,208	85	403	9.3	19.4	3.0	1,727
West North Central	478	63	191	0.3	3.6	5.0	741
South	716	105	310	3.5	26.4	28.6	1,189
South Atlantic	237	35	290	3.5	9.2	13.5	589
East South Central	135	31	19	0.0	17.5	10.2	212
West South Central	342	40	1	0.0	0.1	4.9	388
West	597	38	133	0.0	5.1	8.8	781
Mountain	231	22	27	0.0	3.9	2.7	287
Pacific	366	15	105	0.0	1.2	5.9	494

[*] Totals may not agree because of rounding.

[†] 38×10^6 J/m^3 (1,022 Btu/ft^3).

[‡] 25.1×10^9 J/ℓ (90,000 Btu/gal).

[§] 39×10^9 J/ℓ (140,000 Btu/gal).

[#] 30×10^6 J/kg (26 × 10^6 Btu/ton).

[**] 27.9×10^6 J/kg (24 × 10^6 Btu/ton).

[§§] 13.9×10^6 J/kg (12 × 10^6 Btu/ton).

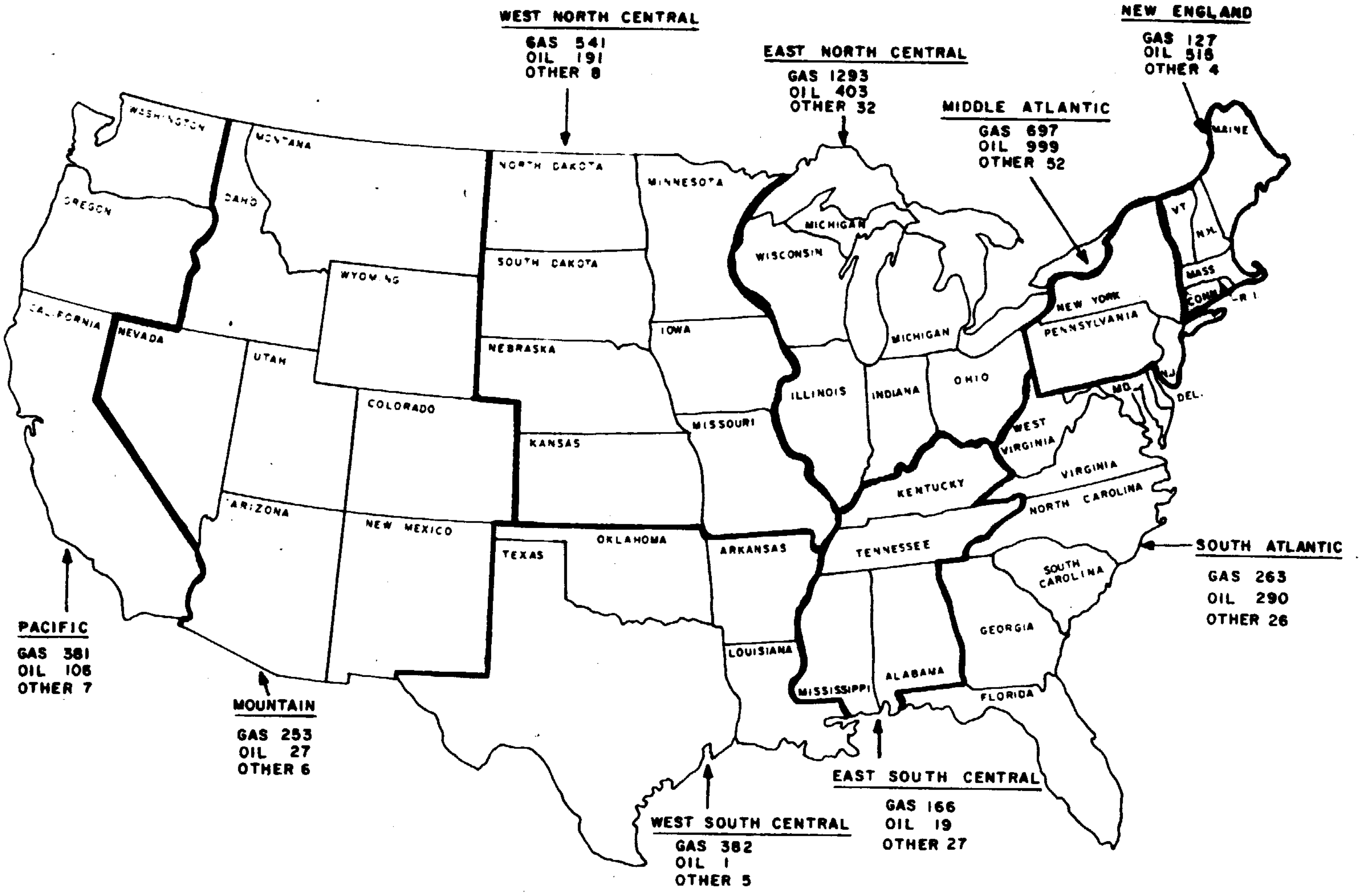


Figure 2. Geographical distribution of residential fuel consumption for space heating, 1975, 10^{15} J/yr.

appeared to be enjoying increased popularity, but again its future has been clouded by the natural gas shortage - a shortage which may be alleviated by importing LNG. Electric heating is also gaining in popularity, particularly in those regions where the winters are less severe. This trend shifts emission problems from the home to the utility. Solar heat for residences is technically, if not economically, feasible at the present time, but probably will not perturb fuel use patterns significantly in the near future. The most crucial unanswered question at the moment is whether or not oil and gas shortages and/or price increases will initiate a significant trend back to coal and/or wood for residential heating. Their increased use as residential fuels will result in increased emissions and require further study.

3.2 POPULATION CHARACTERISTICS

The population distribution of gas- and oil-fired residential sources, based on the heating medium used, is shown in Table 4. In the size range less than 0.16×10^9 J/hr, gas-fired heating systems are 76 to 94 percent warm air furnaces while in the range above 0.16×10^9 J/hr they are 86 percent steam or hot water.[7] A similar, but less pronounced, pattern exists for oil-fired units. New steam or hot water systems are more expensive than warm air systems and are usually installed only in sizes above 0.14×10^9 J/hr.[8]

TABLE 4. POPULATION DISTRIBUTION OF RESIDENTIAL UNITS NOW IN SERVICE, 1974,[7] PERCENT

Type of unit	Rated capacity (10^9 J/hr)		
	0 to 0.1	0.1 to 0.16	0.16 to 0.42
Gas burners			
Steam or hot water	6.1	24.0	85.6
Warm air	93.9	76.0	14.4
Oil burners			
Steam or hot water	28.3	60.5	46.8
Warm air	71.7	39.5	53.2

The size distribution of residential oil-fired sources, based on 1972 data,[2] is presented in Table 5. Some changes from 1972 can be anticipated due to the relative growth of multiunit dwellings. About 69 percent of the units have fuel firing capacities below 0.2×10^9 J/hr. Heating units in the New England and middle Atlantic areas tend to be larger than in other areas.

TABLE 5. SIZE DISTRIBUTION OF RESIDENTIAL OIL-FIRED SYSTEMS, 1972,[2] PERCENT IN SIZE RANGE BY NUMBER

Region	Size (10^9 J/hr)					
	< 0.16	0.16 to 0.2	0.2 to 0.24	0.24 to 0.3	0.3 to 0.44	> 0.44
New England	19.6	43.9	12.8	8.9	7.0	7.8
Mid-Atlantic	24.3	39.7	17.8	8.6	5.7	3.9
South Atlantic	51.8	29.8	9.3	5.7	1.6	1.8
Midwest	44.6	27.1	12.8	8.8	4.4	2.3
West	75.4	14.2	5.9	3.3	0.9	0.3
All sections	34.6	34.7	13.9	8.0	4.9	3.9

Information is also available concerning the population and age of oil burner designs, and this is shown in Tables 6 and 7. High pressure burners predominate. Trend information can be inferred from Table 7, indicating a growth in nonconventional high pressure burners and a decrease in the use of low pressure, rotary, and vaporizing units. Although data are not available, members of fuel oil related institutions indicate that the efficient flame retention burner is now used in the majority of new installations.

Details on the sizes and ages of gas-fired systems are unavailable. It can be assumed that the size distribution will be very similar to oil-fired units and that gas-fired systems may tend to be newer.

3.3 CHARACTERISTICS OF COMBUSTION EQUIPMENT

Residential gas- and oil-fired space heating units are subject to a number of design and operating variations. These variations are related to burner and combustion chamber design, excess air, heating medium, etc. Residential systems operate only in an on/off mode with constant fuel firing rate

TABLE 6. POPULATION OF RESIDENTIAL OIL BURNER DESIGNS, 1972[2]

Region	Percent of total					
	High pressure			Low pressure	Rotary	Vaporizing
	Conventional	Shell head	Flame retention			
	Less than 0.15×10^9 J/hr					
New England	44.9	7.2	14.7	26.4	5.8	1.0
Mid-Atlantic	66.3	8.4	3.8	10.6	8.5	2.4
South Atlantic	74.8	1.9	13.0	0.8	0.1	9.4
Midwest	63.0	9.4	13.1	5.6	8.6	0.3
West	80.3	0.6	5.2	8.1	0.5	5.3
All sections	63.1	7.2	9.1	11.5	6.6	2.5
	0.15 to 0.44×10^9 J/hr					
New England	61.4	7.9	13.6	9.0	7.6	0.5
Mid-Atlantic	69.0	5.2	8.2	10.7	6.8	0.1
South Atlantic	89.4	2.3	7.3	0.8	0.2	-
Midwest	73.3	13.1	6.2	6.0	1.3	0.1
West	80.3	0.6	2.9	13.2	1.8	1.2
All sections	71.2	6.9	8.3	8.6	4.7	0.3
	All oil burners up to 0.44×10^9 J/hr					
All sections	68.3	7.0	8.6	9.6	5.4	1.1

TABLE 7. AVERAGE AGE OF RESIDENTIAL OIL BURNERS, 1972[2]

Region	High pressure			Low pressure	Rotary	Vaporizing
	Conventional	Shell head	Flame retention			
	Years					
New England	13.1	9.5	4.1	14.4	16.8	-
Mid-Atlantic	12.4	8.9	4.2	16.2	17.7	15.6
South Atlantic	10.1	7.0	3.0	19.3	-	13.7
Midwest	14.1	8.8	3.7	17.8	17.8	17.0
West	12.7	7.0	3.7	16.6	-	16.7
All sections	12.6	8.7	3.9	16.5	17.5	15.9

during the "on" cycle in contrast to load modulation encountered with larger commercial, industrial, and utility systems.

The typical oil-fired heating system consists of a burner mounted in a refractory-lined combustion chamber. Flue gas leaves the combustion chamber through a water- or air-cooled heat exchanger. The burner system includes a combustion air blower, fuel pump, spark ignition system, and a fuel nozzle. Fuel flow is determined by the fuel nozzle orifice size while combustion airflow is determined by the blower characteristics and a damper in the flue gas duct.[7] Steam, hot water, or air from the exchanger is usually forced through the heating system by a pump or fan, although gravity or natural draft circulation is used in some instances.

Several burner designs are used for oil atomization[2] as previously shown in Table 6. High pressure atomization burners are the most common, representing 84 percent of total units in 1972 and over 90 percent in 1978. These units operate by forcing oil at a pressure of 100 psig through a small orifice or orifices in the nozzle. The conventional high pressure burner is the most common, but newer designs such as the shell head and retention head are increasing in popularity. These newer burners are designed for improved combustion efficiency and generally result in lower particulate, HC, and CO emissions. SO_x emissions are unchanged, but NO_x emissions may increase due to a more intense, compact flame.

Gas burners are simple and relatively maintenance free compared to oil burners. Most residential gas burners are very similar. They use natural aspiration and consist of three to four venturis with distribution pipes consisting of rows of small orifices. Primary air is aspirated and mixed with the gas as it passes through the venturi. Secondary air enters the furnace around the burners. Flue gases pass through a heat exchanger and a stack. On gas-fired systems, the stack always contains a draft diverter that provides dilution air and prevents downdrafts that could blow out the pilot light.

Typical design and operating characteristics of gas- and oil-fired residential warm air furnaces are presented in Table 8. The large variation in excess air levels presented in Table 8 for the gas-fired systems is due to

TABLE 8. DESIGN AND OPERATING PARAMETERS FOR GAS- AND OIL-FIRED FORCED AIR RESIDENTIAL SPACE HEATING SYSTEMS,[8] HEAT INPUT 1.055×10^8 J/hr

Parameter	Units	Gas-fired sources	Oil-fired sources
Excess air	Percent	20 - 500	10 - 100
Flue exit diameter	Centimeters	8.9 - 12.7	12.7 - 17.8
Heat exchange area	Square meters	0.3 - 3.2	1.9 - 2.8
Overall heat transfer coefficient	$Btu/hr/ft^2/^oF$	2 - 3	2 - 3
Exit flue gas temperature	^oC	232 - 316	260 - 482
Combustion chamber pressure	$Newton/meter^2$	± 50	12 - 50
Temperature rise on air side	^oC	20 - 24	24 - 27
Overall steady state efficiency	Percent	70 - 80	70 - 80

several factors. Because natural gas burners are naturally aspirated, pressures are near atmospheric. Therefore, it is possible to use the natural draft created by the stack to draw the secondary air into the furnace. The amount of secondary air will vary with meteorological conditions.

Air pollution control equipment is not installed on residential heating systems. Excess air, residence time, flame retention devices, and maintenance are major factors in the control of air pollutants and performance of residential units.[9] Proper attention to the above factors can reduce emissions of CO, HC, and particulates. Emissions of NO_x generally tend to remain unchanged when adjustments are made to improve system efficiency and reduce emissions of other pollutants.[2,7]

One of the major factors that reportedly affects particulate, HC, and CO emissions from oil-fired residential systems is cycling. Emissions of particulate, HC, and CO peak during ignition and after burner shutdown.[2,7] However, results obtained during this study and discussed in Section 4 did not confirm these observations for particulates and HC. Emissions of HC and particulates per unit of fuel were essentially unchanged when both gas- and oil-fired units were operated in a 10 minute on/20 minute off cycle as compared to a 50 minute on/10 minute off cycle.

4. EMISSIONS

Air emissions from the flue gas stack are the only significant emissions from gas- and oil-fired residential combustion sources used for space heating. Fugitive emissions from these combustion sources are negligible because the liquid fuels used have low volatility leading to minimum evaporative losses, and the gaseous fuels are for the most part received continuously from a pipe, which must be tightly sealed for safety reasons, rather than via a fuel storage tank and fuel pump.

Although the two residential combustion source categories considered in this study are not major contributors to nationwide pollutant emission totals, they are of potential concern because the sources are numerous and have a close source-receptor relationship. Both source categories ranked high when their total impact on the environment was estimated based on the air impact factor developed by Monsanto Research Corporation (MRC). This air impact factor provides a mathematical ranking of impacts using a model which takes into account the number of sources, the associated population density, ground level concentrations of the pollutants and their environmental hazard potential. The mathematical expression derived by MRC is shown in Appendix C, Attachment B.

4.1 EVALUATION OF EXISTING EMISSIONS DATA

4.1.1 Criteria for Evaluating the Adequacy of Emissions Data

A major task in this program has been the identification of gaps and inadequacies in the existing emissions data base for combustion sources. The results of this effort determine the extent of the sampling and analysis program required to complete an 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 of the data and the variability of the data. A detailed presentation of the procedures used to identify and evaluate emissions data is given in Appendix C. Briefly, the general approach for isolated sources 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 step in the process uses a method developed 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 a source severity factor which is defined as the ratio of the calculated maximum ground level concentration of the pollutant species for a typical source to the level at which a potential environmental hazard exists. If the variability of emission factor data is greater than 70 percent, then the need for further measurement will be based on calculated severity factors for each pollutant. The data will be considered adequate if the upper bound of the source severity factor is less than 0.05 even if the variability is greater than 70 percent.

Severity factors calculated by MRC from nationwide emission estimates[4] for the residential gas- and oil-fired systems considered in this report are all less than 0.05 as shown in Table 9.[10] Normally, as just noted, no further testing would be required. However, in the case of source types such as those considered in this report, which consist of a large number of small sources, additional criteria based on MRC calculated air impact factors (see Appendix C) are used to determine the need for further testing. Application of the criteria described in Appendix C indicated that further testing was required. The environmental significance of emissions from residential sources was evaluated following the measurement program by use of multiple source severity factors using a dispersion model to determine the ambient concentrations from an array of typical residential sources.

TABLE 9. MEAN SEVERITY FACTORS FOR GAS- AND OIL-FIRED RESIDENTIAL SOURCES[10]

Pollutant	Gas-fired sources	Oil-fired sources
Particulates	< 0.0001	0.0001
SO_x	< 0.0001	0.0026
NO_x	0.0010	0.0016
HC	0.0001	0.0001
CO	< 0.0001	< 0.0001
Benzo(a)pyrene	0.0001	0.0001

4.1.2 Sources of Existing Emissions Data

Emissions data for residential gas- and oil-fired heating units have been obtained by the EPA,[9] Battelle,[2,11,12] TRC,[13,14] KVB,[15] Walden Research,[16,17] and the Public Health Service.[18] Most of the data are for the five criteria pollutants (particulates, SO_2, NO_x, HC, and CO), although some measurements of aldehydes, trace metals, and POM emission rates were made. POM measurements were made for both gas- and oil-fired systems, trace metals were measured only for oil-fired units, and aldehydes were measured only for gas-fired systems. Bacharach smoke numbers were also taken for most of the oil-fired systems which were tested. Additional data are now being gathered by other investigators working under EPA sponsorship.

The tests made by TRC, KVB, Walden Research, and the Public Health Service were field tests on burners in the "as found" condition. The EPA data were obtained in laboratory tests of burners which were well tuned. Battelle performed three studies (1971,[11] 1973,[2] and 1974[12]), two of which (1971 and 1973) involved field testing. In these studies, emission rates were measured before and after tuning. The other study (1974) was done in the laboratory.

4.1.3 Existing Emissions Data: Gas-Fired Sources

The data used to evaluate the status of the existing data base are presented in Appendix D for gas- and oil-fired residential sources. A summary of the data is presented below along with the conclusions drawn from evaluation of the adequacy of the data.

Emission rates of particulates, SO_2, NO_x, HC, CO, and aldehydes from gas-fired sources were measured by TRC,[13,14] Battelle (1971),[11] EPA,[9] and KVB.[15] One hundred units were tested by TRC, two units by Battelle, four units by EPA, and thirty-one units by KVB. Data from all studies were combined and mean emission rates, the standard errors and variability of the means, and the severity factors calculated. This information along with EPA emission factors[3] is presented in Table 10. There are significant differences in the results of the various studies used to compile Table 10, particularly in the case of particulates, HC, and CO emissions. Emissions of SO_2 and NO_x were in reasonable agreement with EPA emission factors.

TABLE 10. SUMMARY OF EXISTING EMISSIONS DATA FOR GAS-FIRED RESIDENTIAL SOURCES

Pollutant	Number of units	Mean (ng/J)	Standard error (ng/J)	Variability (%)	Severity* factor	EPA emission factor[3] (ng/J)
Particulates†	101	0.41	0.10	49	8×10^{-6}	2 - 6
SO_2	9	0.21	0.15	164	3×10^{-6}	0.26‡
NO_x	133	56.6	4.1	15	5×10^{-3}	33
HC	98	39.4	5.8	29	2×10^{-3}	3.3
CO	105	38.7	8.3	43	8×10^{-6}	8.4

*Based on a firing rate of 99×10^6 J/hr.

†Filterable particulate.

‡Based on a fuel sulfur content of $4{,}600\ g/10^6\ Nm^3$.

Most of the available particulate emissions data is for filterable particulate. The mean emission factor of 0.41 ng/J is based almost entirely on data obtained by TRC, using nonstandard sampling methods, and is a factor of 5 to 10 lower than the Battelle data and the EPA emission factor. TRC further reported that filterable particulates made up only about 2 percent of total particulate emissions. This is in contrast to the result obtained by Battelle in a single test. Battelle reported that about one-third of the total particulate was filterable. Further testing should be conducted to resolve the above differences. In the case of HC and CO emissions, TRC values exceeded those measured by EPA and Battelle by a factor of 10 and 4, respectively. The discrepancy cannot be attributed to the test methods used, as was true of the particulate emission values, and further testing should be conducted, particularly in the case of HC because of its higher severity factor.

The Public Health Service measured the emissions of POM from three residential gas-fired heating units, as shown in Table 11. 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. The mean emission factor for total benzene-soluble organics was 2,150 pg/J. Measures of variability such as standard errors are not shown in the table. Since there is only one measurement for three source types, no meaningful measure of variability is possible.

TABLE 11. POM EMISSIONS FROM GAS-FIRED RESIDENTIAL SOURCES,[18] pg/J

Pollutant	Heating unit		
	Double shell boiler, 0.19 GJ/hr input	Hot air furnace, 0.22 GJ/hr input	Wall space heater, 0.03 GJ/hr input
Total benzene-soluble organics	900	620	4,920
Benzo(a)pyrene	< 0.02	< 0.02	0.26
Pyrene	0.16	0.11	15.2
Benzo(e)pyrene	ND	0.02	1.40
Perylene	ND	ND	ND
Benzo(ghi)pyrene	ND	ND	2.20
Anthanthrene	ND	ND	0.07
Coronene	ND	ND	0.79
Anthracene	ND	ND	ND
Phenanthrene	ND	0.07	ND
Fluoranthene	0.30	0.10	7.60

ND - Not Detected.

Significant quantities of trace elements are not present in natural gas, and measurements are not justified except for purposes of confirmation.

4.1.4 Existing Emissions Data: Oil-Fired Sources

The results of tests in which emission rates of total particulates, SO_2, NO_x, HC, and CO were measured for oil-fired units are presented in Appendix D. Information about the condition of the units tested, such as age, efficiency, excess air, and stack gas compositions, is also presented. The tests were carried out by Battelle and EPA. Data from Walden Research is also shown, although no criteria pollutant data were obtained in their study of oil-fired source operations.

Data from the EPA and Battelle studies were combined. The mean emission factors calculated from these tests are shown in Table 12. Standard errors and variabilities of the mean, severity factors, and EPA emission factors are also shown in Table 12.

TABLE 12. SUMMARY OF EXISTING EMISSIONS DATA FOR OIL-FIRED RESIDENTIAL SOURCES

Pollutant	Number of units	Mean (ng/J)	Standard error (ng/J)	Variability (%)	Severity* factor	EPA emission factor[3] (ng/J)
Particulates†	35	24.9	5.2	42	1.4×10^{-3}	7.7‡
SO_2	20	93.0	7.1	15	3.8×10^{-3}	106§
NO_x	58	43.8	3.0	13	1.1×10^{-2}	55
HC	59	10.2	6.1	121	1.4×10^{-3}	3
CO	61	47.4	16.0	67	3.1×10^{-5}	15

*Based on a firing rate of 298×10^6 J/hr.

†Total particulate.

‡Filterable particulate.

§AP-42 gives the SO_2 emission factor as 142 S lb/1000 gal, where S is the fuel sulfur content. In tests of 20 residential fuel oils, Battelle (1971) found the average sulfur content to be 0.24 percent. This content was used to calculate the emission factor.

converted to 2.5 lb/10³ gal which is AP-42 for domestic [illegible]

As shown in Table 12, the average emission factors for SO_2 and NO_x are in reasonable agreement with EPA emission factors. In the case of the particulate emission data, which was obtained by Battelle, the average emission factor is three times greater than the EPA emission factor of 7.7 ng/J. However, filterable particulate data obtained from the same units averaged about 40 percent of the total particulate. Battelle's emission factor estimate for filterable particulate is, therefore, about 8.8 ng/J. The measured HC emission factor shown in Table 12 is three times greater than the EPA emission factor. The average value, however, is highly influenced by the inclusion of data from two units tested by Battelle. If these two data points are not included in the summary, the mean emission factor drops to about 2 ng/J. Similarly in the case of CO emissions, the exclusion of four high emission values from the data summary reduces the mean emission factor to 17 ng/J, a value close to the EPA emission factor of 15 ng/J.

The Public Health Service measured the emissions of POM from three residential oil-fired heating units, as shown in Table 13.

TABLE 13. POM EMISSIONS FROM OIL-FIRED RESIDENTIAL SOURCES,[18] pg/J

Pollutant	Heating unit		
	Cast iron boiler, 0.25 GJ/hr input	Hot air furnace, 0.15 GJ/hr input	Hot air furnace, 0.09 GJ/hr input
Total benzene-soluble organics	7,700	3,400	3,300
Benzo(a)pyrene	< 0.04	< 0.06	< 0.11
Pyrene	1.70	0.01	1.10
Benzo(e)pyrene	ND	ND	ND
Perylene	ND	ND	ND
Benzo(ghi)pyrene	ND	ND	ND
Anthanthrene	ND	ND	ND
Coronene	ND	ND	ND
Anthracene	ND	ND	ND
Phenanthrene	8.40	ND	ND
Fluoranthene	4.70	0.07	14.20

ND - Not Detected.

For the measurements shown in Table 13, 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. The mean emission factor for total benzene-soluble organics was 4,800 pg/J. Variability data have not been calculated because of the limited number of tests.

In their 1971 study, Battelle measured the emission rates of some trace metals in particulate matter for one burner in the "as found" condition (Unit 26, Appendix D). Particulates were collected using a revised version (no cyclone was used) of EPA Test Method 5. The probe wash, impinger wash, and filter catch were analyzed for trace metals using optical emission spectrometry. Emission rates were determined for all of the metals detected: iron, boron, silicon, magnesium, manganese, lead, nickel, aluminum, copper, calcium, chromium, barium, bismuth, cobalt, potassium, tin, vanadium, silver, sodium, zinc, and titanium. The emission rates are presented in Table 14. Since only one burner was tested, it is impossible to calculate variability of the data.

4.1.5 Status of Existing Emissions Data Base for Gas- and Oil-Fired Residential Sources

In summary, the evaluation of the adequacy of existing emissions data on the basis of variability and severity factor criteria for gas- and oil-fired residential heating units has led to the findings shown in Table 15.

4.2 EMISSIONS DATA ACQUISITION

4.2.1 Selection of Test Facilities

Because residential combustion sources are associated with areas of high population density, operate at relatively low efficiency, and emit pollutants at essentially ground level, emissions from these combustion sources have been regarded with some concern. The concern is largely due to the inadequacy of the previously described existing emissions data base. The combination of the potential for significant air pollution impact and data inadequacy led to a decision to test five gas-fired and five oil-fired residential sources. This

TABLE 14. TRACE METAL EMISSIONS FROM AN OIL-FIRED BURNER[11]

Element	Emission factor (pg/J)				Severity factor
	Probe wash	Filter catch	Impinger wash	Total	
Fe	0.49	5.53	9.89	15.9	0.0018
B	0.10	< 0.98	1.97	2.0 - 3.0	10^{-4}
Si	1.97	0	24.57	26.5	0.018
Mg	0.68	0.49	9.83	11.0	10^{-4}
Mn	< 0.10	< 0.40	0.30	0.3 - 0.8	10^{-4}
Pb	< 0.68	7.37	1.97	9.2 - 9.8	0.0075
Ni	< 0.10	0.49	0.68	1.2 - 1.3	10^{-4}
Al	0.68	14.74	14.74	30.2	10^{-4}
Cu	0.30	< 0.98	2.98	3.0 - 4.0	10^{-4}
Ca	0.98	1.47	29.80	32.3	10^{-3}
Cr	< 0.10	ND	0.98	1.0 - 1.1	0.0024
Ba	0.10	< 0.98	1.97	2.0 - 3.0	10^{-3}
Bi	ND	< 0.40	ND	< 0.40	-
Co	< 0.10	ND	2.98	3.0 - 3.1	0.003
K	< 0.98	< 29.5	9.83	10.0 - 40.0	0.003
Sn	0.10	ND	2.98	3.1	10^{-4}
V	< 0.10	ND	< 0.10	< 0.2	10^{-5}
Ag	< 0.10	ND	0.10	0.1 - 0.11	10^{-3}
Na	< 0.98	ND	67.56	67.5 - 68.5	0.006
Zn	< 0.98	ND	2.98	3.0 - 4.0	10^{-4}
Ti	0.20	ND	0.80	1.0	10^{-5}

ND - Not Detected.

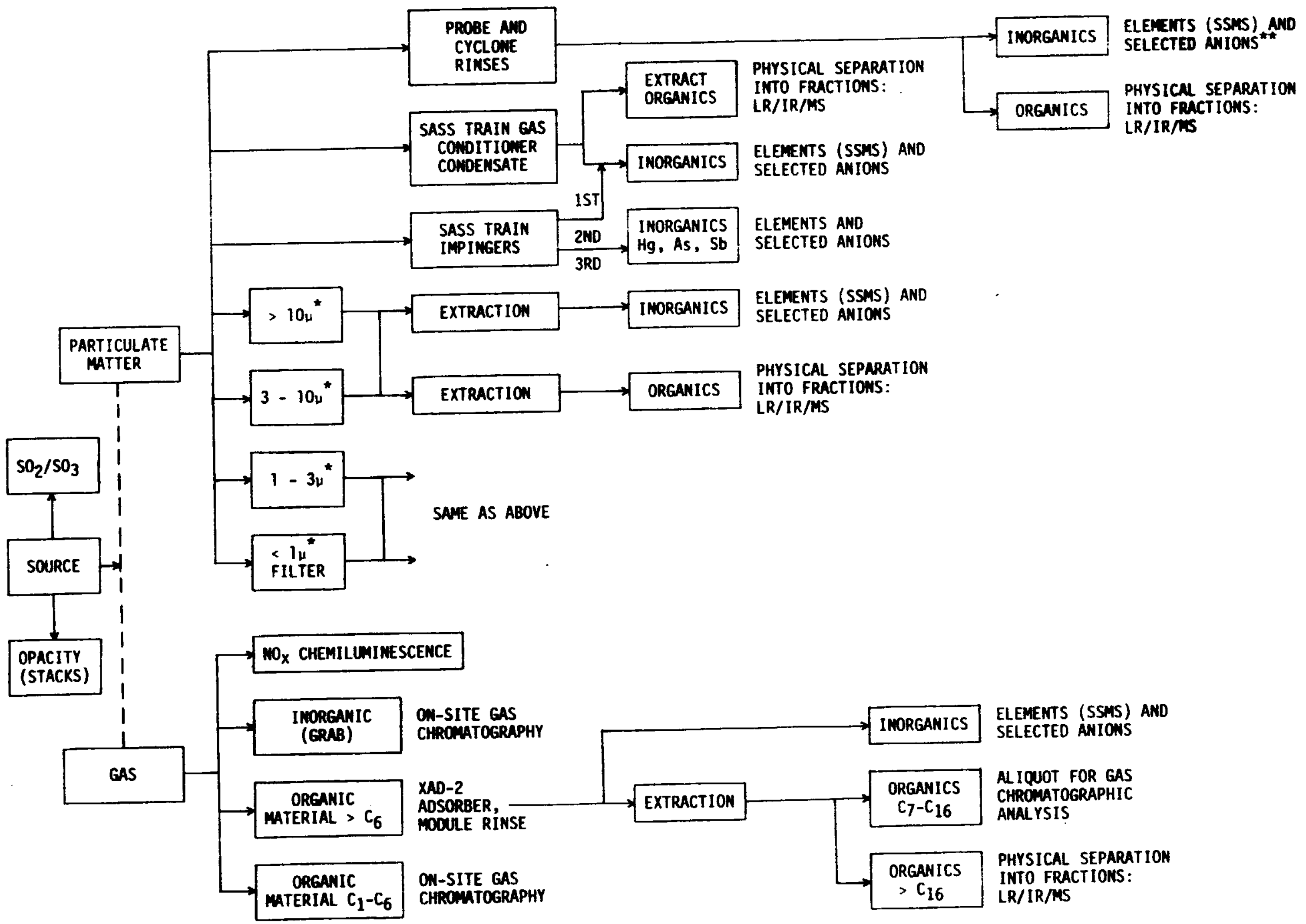
TABLE 15. SUMMARY OF EVALUATION OF EXISTING EMISSIONS DATA

Pollutant	Emission factor (ng/J)	Variability (%) (criterion: < 70)	Severity factor (criterion: < 0.05)	Comments concerning data requirements
Gas-fired sources				
Particulates	0.4	49	8×10^{-6}	Further tests required due to data inconsistency
SO_2	0.2	164	3×10^{-6}	No further tests required
NO_x	56.6	15	5×10^{-3}	No further tests required
HC	39.4	29	2×10^{-3}	Further tests required due to data inconsistency
CO	38.7	43	8×10^{-6}	No further tests required
POM	2.2	-	-	Further tests required
Trace elements	-	-	-	No significant quantities in gaseous fuel, test for confirmation only
Oil-fired sources				
Particulates	24.9	42	1.4×10^{-3}	No further tests required
SO_2	93.0	15	3.8×10^{-3}	No further SO_2 data required, but SO_3 data are lacking
NO_x	43.8	13	1.1×10^{-2}	No further tests required
HC	10.2	121	1.4×10^{-3}	No further tests required
CO	47.4	67	3.1×10^{-5}	No further tests required
POM	4.8	-	-	Further tests required
Trace elements	0 - 30 pg/J	-	0.018 - 10^{-5}	Further tests required for confirmation

is the maximum number of test sites being studied by modified Level I sampling and analysis for any source category in the total program. The basic Level I sampling and analysis scheme is shown in Figure 3.

Following a review of the initial data obtained from testing of the 10 selected residential sites, it was decided that further testing was warranted to resolve questions concerning certain aspects of the test program. A major concern was the selection of the 50 minute on/10 minute off cycle used at all 10 residential test sites, as opposed to a 10 minute on/20 minute off cycle used in other studies[9,11] of residential emissions. These studies have reported that hydrocarbon emissions peak during startup and shutdown of the burner. The fivefold increase in the number of cycles required for the 10/20 cycle should result, therefore, in an increase in emissions. Further, it was postulated that, because of lower furnace and flame temperatures, the 10/20 cycle could lead to increased organic emissions and considerably greater POM emissions. The effect of cycle mode on organic emissions was subsequently measured at one gas-fired and two oil-fired sites. Additional testing involved Level II analysis for SO_2, SO_3, and particulate sulfate emissions from the oil-fired sites, and parameter checks of all test units to determine if their operations were within the normal range of residential furnace operation. All of the oil-fired units were serviced during the months of September and October prior to both of the two test periods. One unit, gas-fired site 103, which had emitted high levels of C_1-C_3 organics during the first series of tests, was found to be defective, and these C_1-C_3 values are not included in estimations of organic emission rates and severity factors presented in this report.

The choice of specific sites is based on the representativeness of the sites as measured against important characteristics of systems within each source category. Typical values for important characteristics; e.g., burner type and age, firing rate, and types of systems, were obtained from the data base (see Section 3). The gas-fired units selected for testing were warm air furnaces which comprise over 90 percent of units in the size range tested ($< 1.0 \times 10^8$ J/hr). Both warm air and forced hot water oil-fired systems were tested. All of the oil-fired systems used conventional high pressure burners, the type of burner used in 68 percent of oil-fired home heating



*Weigh individual catches.

**If inorganics are > 10% of total catch.

Figure 3. Basic Level I sampling and analytical scheme for particulates and gases.

systems. As will be discussed in the results section, all of the units tested exhibited acceptable combustion characteristics, as determined by the parameter checks, with the exception of sites 103, 129, and 326. High CO values were measured at these sites.

The manufacturer, rated capacity, and age of the units selected for testing are shown in Table 16. While it is common practice in the case of oil-fired sources to replace burner nozzles at frequent intervals, often on a yearly basis, burner age is still important to provide some indication of the age of moving parts and parts exposed to high temperatures.

4.2.2 Field Testing Procedures

Field testing procedures were based on Level I environmental assessment methods. The SASS train was used to collect particulate, organic, and trace metal samples at the exit of the stack. This sampling train (Figure 4) is a high volume (approximately 0.14 m^3 per minute) system designed to extract particulates and gases from the stack, separate particulates into four size fractions, trap organics in an adsorbent, and collect volatile trace metals in liquid solutions. A high volume system is required to collect adequate quantities of trace materials for subsequent laboratory analyses. The train is constructed such that all sample contacting surfaces are of type 316 stainless steel, Teflon, or glass.

The residential combustion tests were carried out without the cyclones in the SASS train due to the low concentrations of particulates and their characteristic small particle diameters. The 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 the XAD-2 resin (a styrene, divinylbenzene copolymer). The gas then passed through an impinger containing a hydrogen peroxide solution to collect oxidizable constituents. A second impinger with a solution of ammonium peroxydisulfate and silver nitrate and a third impinger containing ammonium perosydisulfate solution were used to collect any volatile trace elements not collected in upstream SASS sections. A fourth impinger containing silica gel was used to remove the remaining moisture from the sample stream.

TABLE 16. CHARACTERISTICS OF RESIDENTIAL COMBUSTION UNITS TESTED

Combustion source type	Site no.	Manufacturer	Burner type	Heating medium	Rated capacity* (Btu/hr)	Age (yr)
Gas-fired	100/127	Gaffers & Sattler, Model 580	Conventional	Forced air	80,000	14
	101/128	Gaffers & Sattler, Model 580	Conventional	Forced air	80,000	8
	102/125	Day and Night, Model C 80 U, Series 510	Conventional	Forced air	80,000	12
	103/126	Sears Homart, Model 735	Conventional	Forced air	100,000	20
	104	Sears Homart, Model 735	Conventional	Forced air	75,000	6
	129/130/131	Rheem, Model 3204-80	Conventional	Forced air	80,000	15
Oil-fired	300/300-2	American Standard, Model MF-A	Conventional high pressure	Forced hot water	182,000	27
	301/301-2	American Standard, Model W0391	Conventional high pressure	Forced hot water	175,000	25
	302/302-2	General Electric No. 5 KI, ME-1 Burner	Conventional high pressure	Forced air	78,000	21
	303/303-2	U Labs No. L8626 LD	Conventional high pressure	Forced air	112,000	5
	304	Embassy Steel Products	Conventional high pressure	Forced air	87,000	16
	326-1/326-2	Arcoliner No. W.O. 351, Series 3AS3	Conventional high pressure	Forced air	141,000	16
	327-1/327-2	Armstrong, Model L61-95 A527	Conventional high pressure	Forced air	120,000	6

*1 Btu/hr is equivalent to 1,055 J/hr.

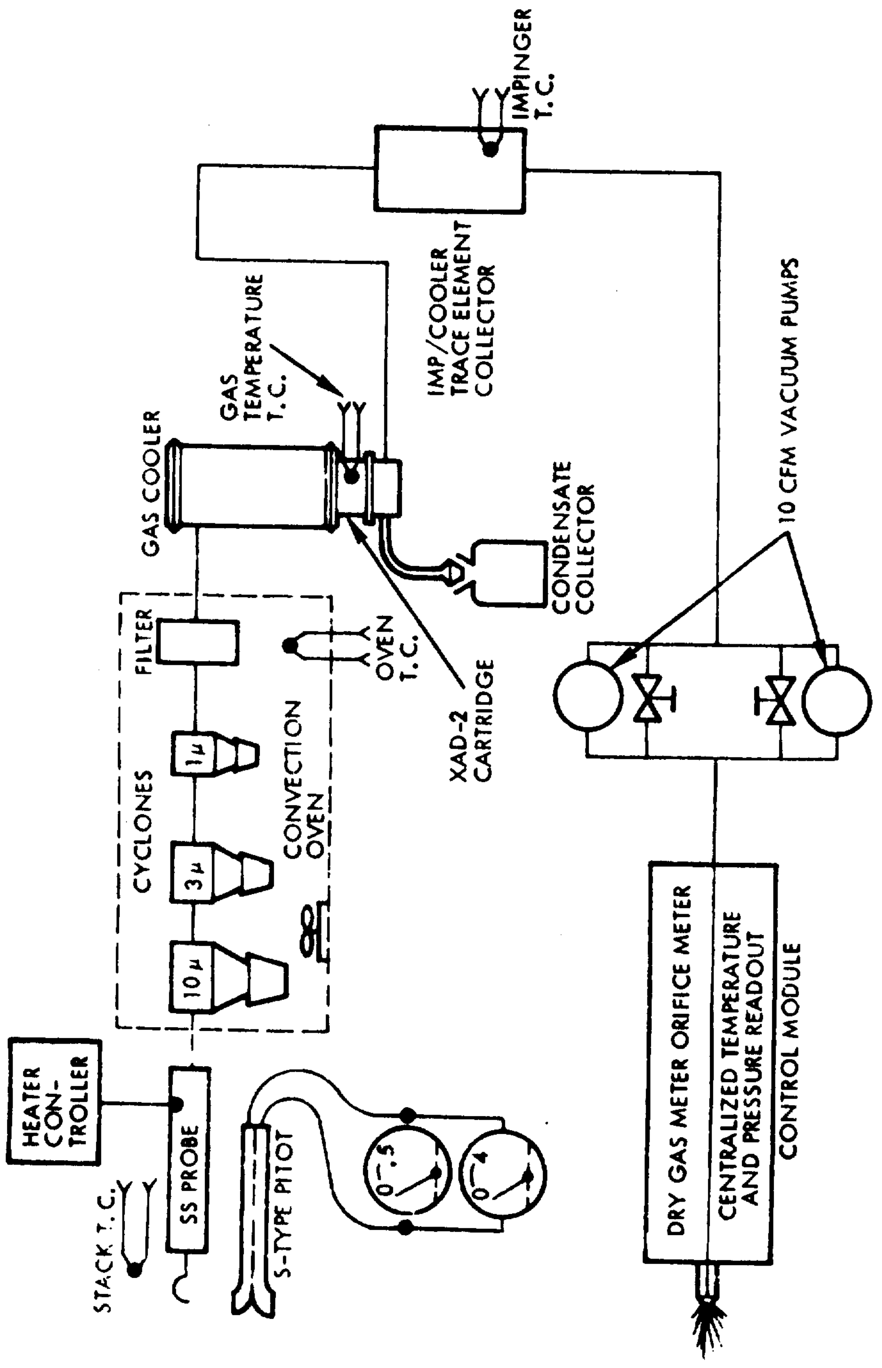


Figure 4. SASS schematic.

Samples of the flue gas were obtained using a 1-meter probe with a 1.6-centimeter nozzle at a single traverse point approximating the average flow rate of the flue gas, as determined by a multipoint traverse. Sample 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. Additional sampling time was required to obtain 90 cubic meters of sample volume in the case of the five oil-fired sites initially tested. The longer sampling time was required to provide samples to EPA for additional analyses. Sampling locations for an oil-fired residential unit are shown in Figure 5.

Samples of the flue gas were collected for on-site analyses of flue gas constituents using a stainless steel probe, condenser, diaphragm pump and gas sampling bags. The collected samples were injected into a gas chromatograph through a heated gas sampling valve for analysis. Low molecular weight hydrocarbons with boiling points below 100°C were measured in the field using a flame ionization detector. Other flue gas constituents, CO_2, O_2, and CO were measured using a thermal conductivity detector. Standard mixes of the gases were used for calibration.

In the second series of tests conducted in 1978, measurement of combustion parameters was conducted at both the stack and furnace locations shown in Figure 5 in order to improve characterization of furnace operating conditions. Combustion parameter measurements of CO_2, O_2, CO, and smoke spot numbers were conducted at both the previously tested sites and the new sites selected for the study of burner duty cycle. CO detection tubes were used in these tests because GC detection limits were well above the normal CO concentration range of the combustion gases. Smoke spot numbers were determined at the furnace exit location using a Bacharach smoke spot tester.

The two oil-fired residential heating units tested in 1978 (sites 326 and 327) were sampled at the stack exit for SO_2, SO_3, and particulate sulfate using a Level II controlled condensation system (CCS), which is a Goksöyr-Ross procedure modified by TRW. The CCS sampling train, shown in Figure 6, consists of a quartz nozzle; a heated quartz probe liner; a heated quartz filter holder containing a quartz filter; a Pyrex modified Graham condenser; three impingers, the first containing 3 percent hydrogen peroxide, the second empty, and the third containing silica gel; a dry gas meter; and a leakless pump.

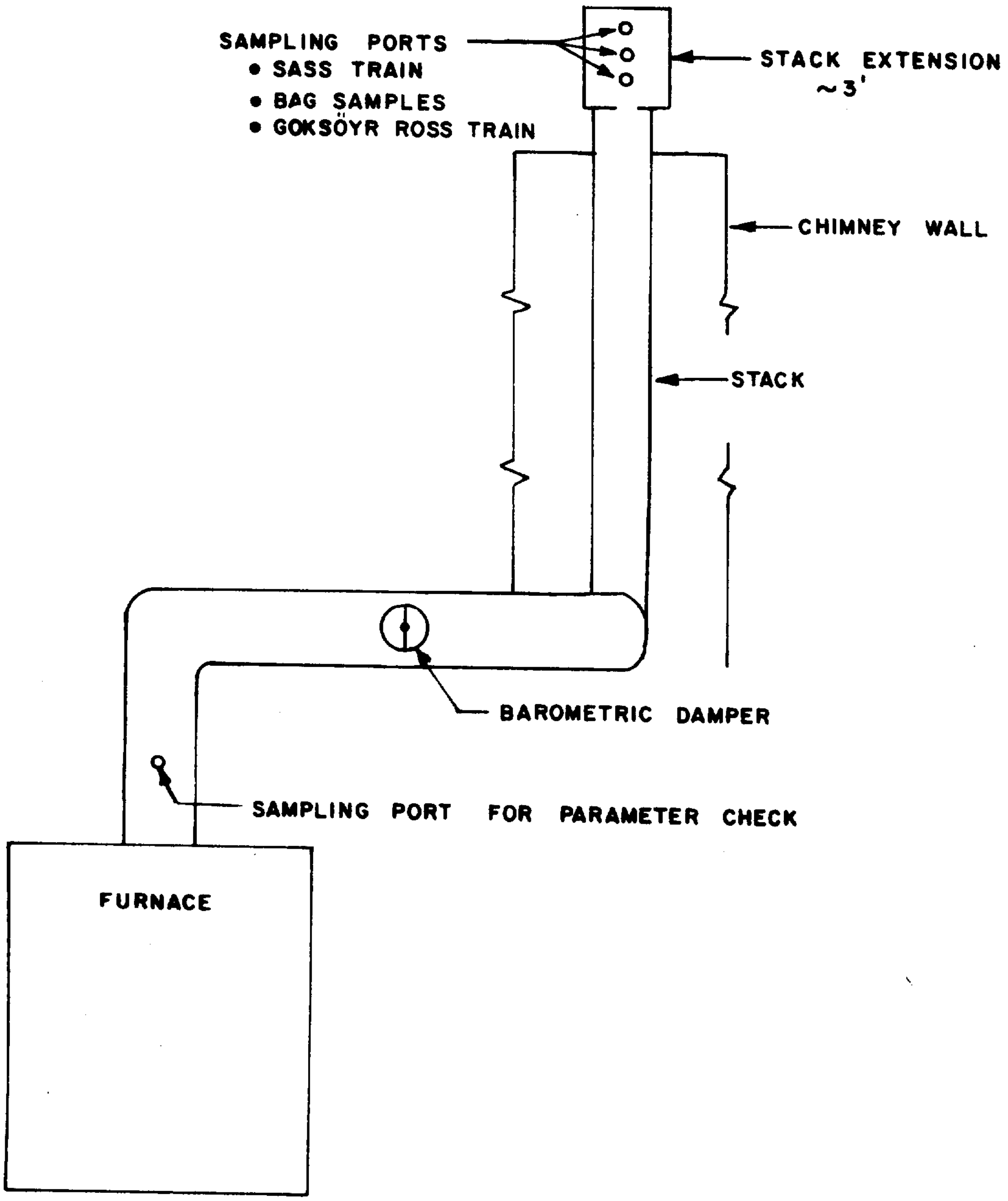


Figure 5. Sampling locations for oil-fired residential sources.

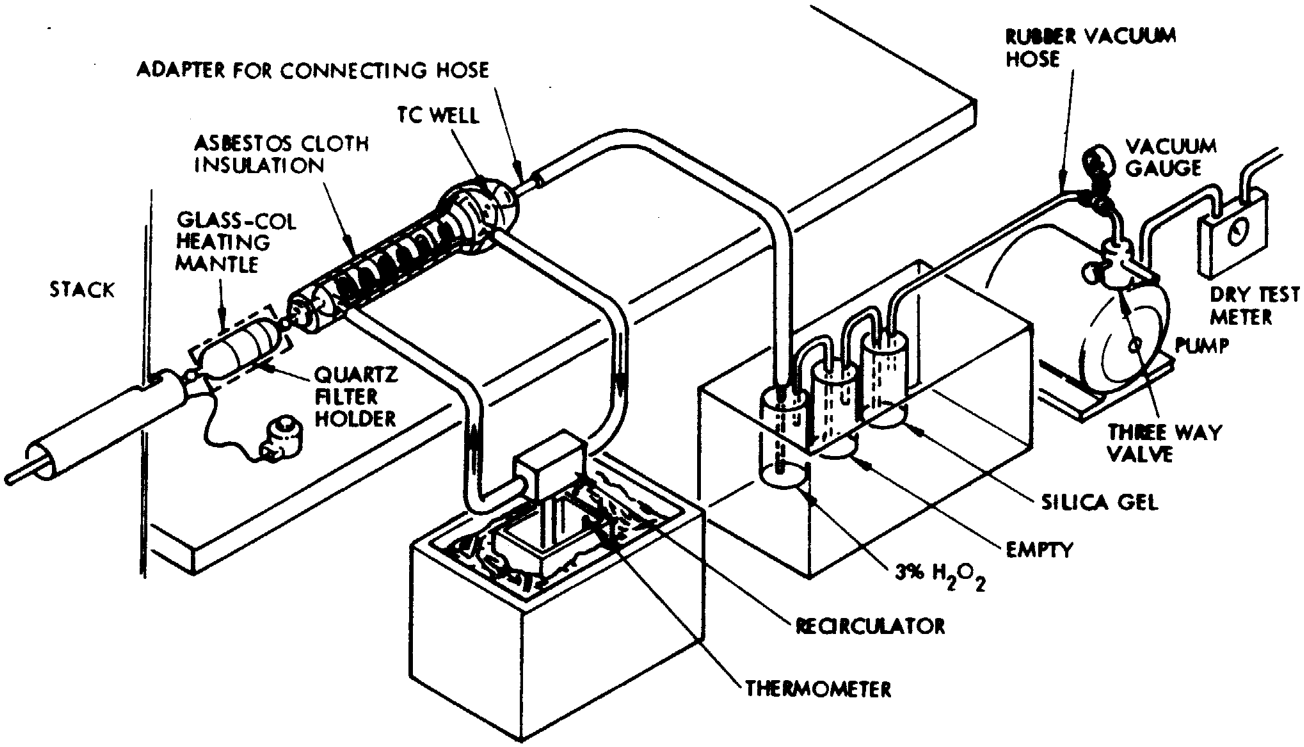


Figure 6. Schematic of controlled condensation system.

For sampling, the nozzle is oriented into the gas stream and sample gas is withdrawn at a constant rate (0.3 liter/minute). The gas temperature is kept above the dewpoint of sulfuric acid through the probe and filter holder to ensure that only particulate sulfate is filtered. The condenser, however, is maintained at a temperature below the acid dewpoint by a heated circulating water bath which causes the SO_3 in the sample gas to condense out as sulfuric acid. Sulfur dioxide remains in the gas phase. Subsequently, the SO_2 is withdrawn from the sample gas in the solution of the first impinger where it is oxidized to sulfate. Sample recovery consists of combining the filter and the particulate recovered from the probe for measurement of particulate sulfate, flushing the condenser coil several times with distilled deionized water for recovery of SO_3, and packaging the contents of the first impinger for SO_2 analysis.

Sample recovery, including precleaning and handling of sample containers, of SASS and Goksöyr-Ross train components was carried out according to Level I procedures and specifications.[1]

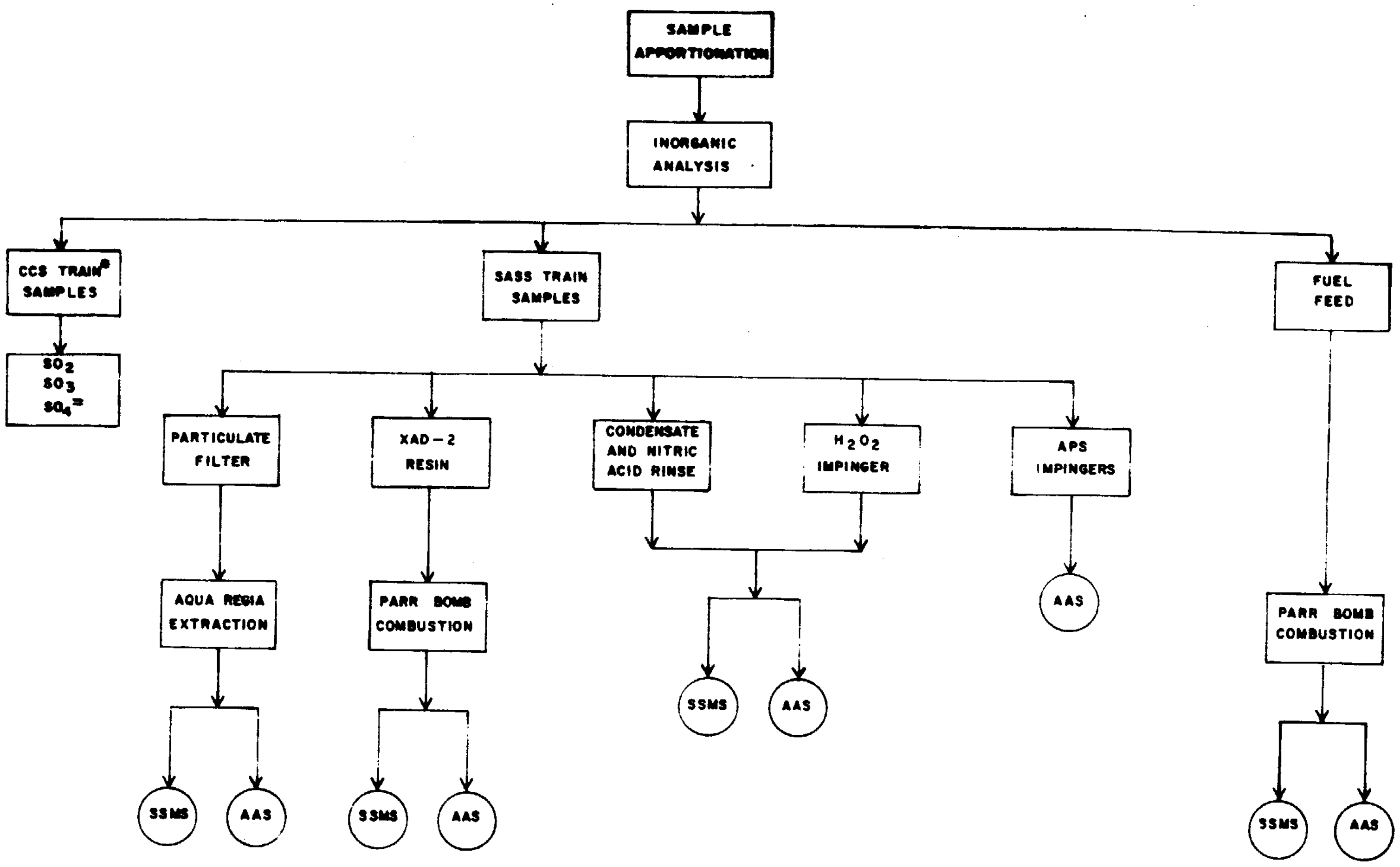
4.2.3 Laboratory Analysis Procedures

The laboratory analysis procedures used to characterize the residential sources sampled during this portion of the program are summarized below. In general, the analytical scheme of IERL's Level I Procedures Manual[1] was followed. More details are given in "Emissions Assessment of Conventional Stationary Combustion Systems: Methods and Procedures Manual for Sampling and Analysis," EPA-600/7-79-029a, January 1979.

4.2.3.1 Inorganic Analysis--

The inorganic analytical scheme consisted of a SSMS elemental survey analysis for the determination of some 70 elements and Atomic Absorption Spectrometric (AAS) analysis for mercury, arsenic, and antimony. The analytical scheme is depicted schematically in Figure 7.

As shown in Figure 7, the flue gas sampled by the SASS train produced four laboratory samples for inorganic analysis. The particulate filter (PF), the XAD-2 resin (XR), and a composite sample (CH) containing portions of the XAD-2 module condensate, the HNO_3 rinse of the module, and the first impinger



*LEVEL II ANALYSIS

Figure 7. Level I inorganic analysis methodology for residential sources.

were analyzed by AAS and SSMS. AAS analysis was also conducted on the second and third impinger composite sample (CI). In addition, for the oil-fired sources, the fuel feed was analyzed for trace metal composition.

Figure 7 also indicates the sample preparation steps which were used to prepare the samples for laboratory analysis. For the primarily organic materials, XAD-2 resin, and fuel oil, a Parr oxygen bomb combustion of the sample was employed in order to eliminate the organic matrix. The particulate filters were extracted with aqua regia to facilitate analysis. No preparative steps were necessary for the impinger composite samples.

The complete analytical scheme was implemented for the five gas-fired and five oil-fired sources initially tested. A review of the resulting data indicated that no significant trace metal emissions are produced by the gas-fired sources. The data analysis also showed that the trace metal emissions from oil-fired sources can be adequately characterized by analyzing the fuel feed. Therefore, in the later series of tests of residential sources, inorganic characterization of the oil-fired sites was restricted to a fuel feed analysis. No inorganic analyses were conducted for the gas-fired sources sampled in 1978.

The two residential oil-fired sites sampled to evaluate cyclic effects were also tested for SO_2, SO_3, and particulate sulfate using the Goksöyr-Ross sampling train. This Level II procedure was instituted because of inadequacies in the data base with regard to SO_3 and particulate sulfate emissions.

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

- SSMS -- SSMS was used in the laboratory to perform a semiquantitative elemental survey analysis on all types of Level I samples. The analysis was 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 which are decomposed and subsequently analyzed by a mass determination using a double-focusing mass spectrometer. Decomposition of the sample electrodes is accomplished by the application of a radio frequency (~1 MHz) potential of about 4 kV. This 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 which 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 two 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 evaporating the sample to fumes of sulfur trioxide. The antimony liberated is subsequently reacted with potassium iodide and stannous chloride, and finally with sodium borohydride to form stibine. The stibine is 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. Since the stibine is freed from the original sample matrix, interferences in the flame are minimized.

- Goksöyr-Ross Analysis for SO_2, SO_3, and Particulate Sulfate -- Four separate analyses are done for the Goksöyr-Ross samples. The particulate matter, which includes filter and probe rinse particulates, is analyzed for sulfate. The filter is allowed to desiccate overnight and is weighed. The probe rinse (acetone) is evaporated to dryness in air and the particulate weight recorded. This is then combined with the filter and extracted with hot water. The hot water extract is analyzed and reported as water soluble sulfate. Any solids remaining from the hot water extraction are extracted in hot hydrochloric acid; the extract is analyzed and reported as water insoluble sulfate.

  The coil rinse (water) is analyzed by an acid-base titration against 0.02 N sodium hydroxide which has been standardized against primary standard potassium acid phthalate. The results are reported as mg SO_3.

  The peroxide impinger is analyzed by titration with standard barium perchlorate. Prior to the titration, sodium carbonate is added to bring the pH into the range of 8.9, and the sample is boiled to remove peroxide. The results are reported as mg SO_2.

4.2.3.2 Organic Analysis--

Level I organic analysis is designed to provide a semiquantitative (± 3) determination of the classes and concentrations of organic substances contained in waste streams emitted by stationary energy and industrial processes. In general, three categories of organic compounds are defined according to their boiling points (BP) by Level I: gaseous, volatile, and nonvolatile. Gaseous organics boiling below 100°C, which are measured in the field, have been discussed earlier. Volatile organics are defined as those which boil between 100° and 300°C; nonvolatile organics boil above 300°C. Organic analyses were performed on all SASS train components except the impingers. All stainless steel components were rinsed with methylene chloride or a 50/50 (v/v) mixture of methylene chloride/methanol to recover organics. Organics in the condensate, particulate filter, and XAD-2 resin were recovered by methylene chloride extraction.

Sample collection and laboratory analyses were performed during two different time periods (summer 1977 and spring-summer 1978). In the interim, procedural changes were made in the Level I sampling and analytical methods. These changes are described, as appropriate, in the following discussion of specific procedures and analyses.

The laboratory analysis scheme and decision criteria for residential sources are depicted in Figure 8. All organic liquids and solvent extracts were first concentrated to 10 mℓ in a Kuderna-Danish (K-D) evaporator, with the concentrated samples then analyzed in two stages. The first stage of the analysis consisted of four different methods. A sample aliquot was evaporated to dryness and weighed. The residue was then taken up in methylene chloride, transferred to salt plates, the methylene chloride evaporated, and its IR spectrum scanned between 2.5 and 15 microns by a grating IR spectrophotometer. The output of these steps was, respectively, a measure of the amount of nonvolatile organic matter ($> C_{16}$) present in each sample and an indication of the functional groups present.

Another sample aliquot was injected into a gas chromatograph (GC). The instrument was calibrated so that the organic compounds boiling between 100 and 300°C (i.e., C_7 to C_{16}, the total chromatographable organics or TCO) were quantified relative to n-decane. If the TCO was greater than 75 $\mu g/m^3$, the quantity of organics boiling within specific ranges was also determined. For samples from the initial five gas-fired and five oil-fired sources (sites 100 through 104 and 300 through 304), compounds boiling in the range 110 to 220°C (C_8 to C_{12}) were determined. In the later tests (sites 129, 326, and 327), procedure modifications were made in order to quantify organics over the full 100 to 300°C BP range.

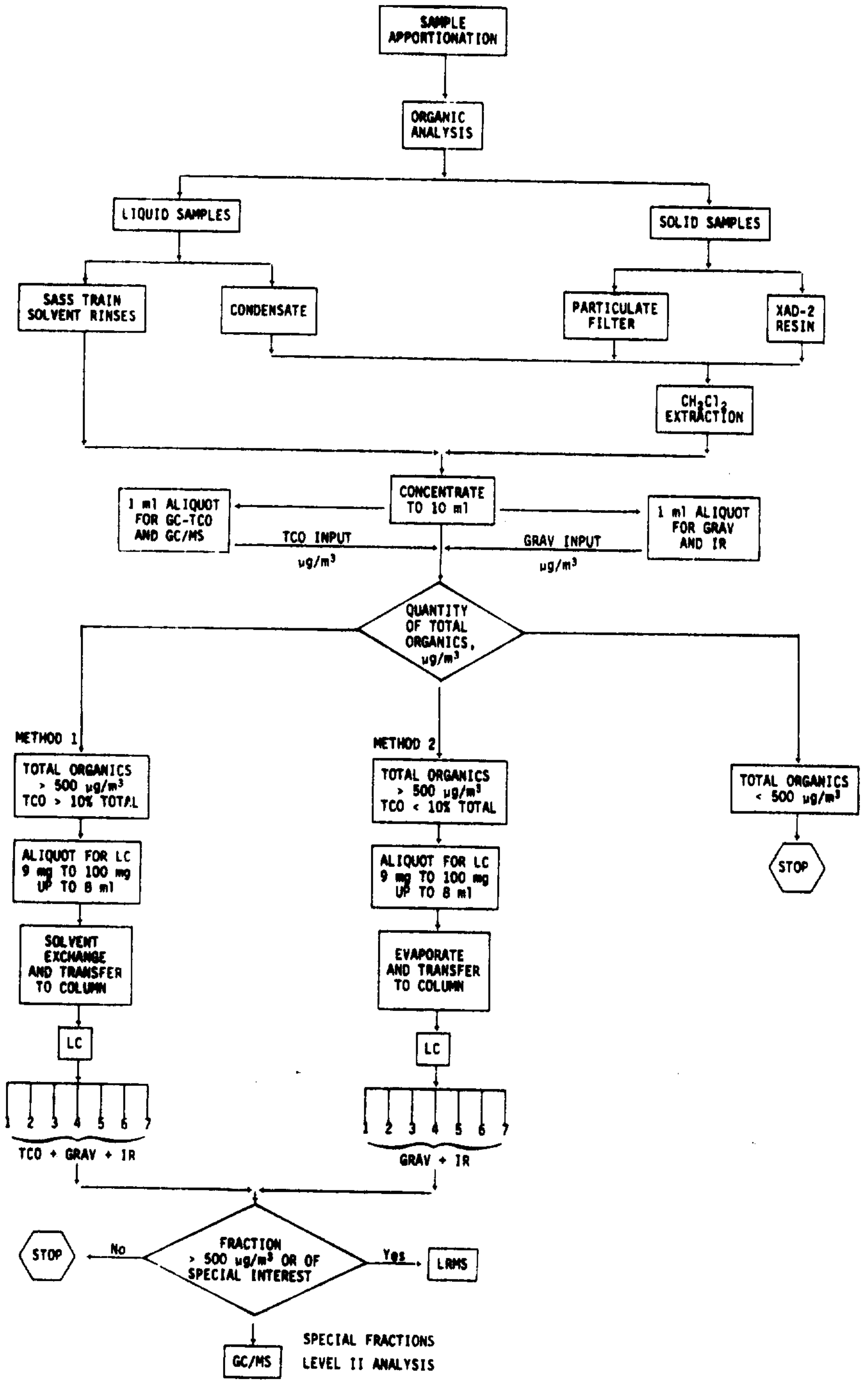


Figure 8. Level I organic analysis methodology for residential sources.

As shown in Figure 8, the samples were not analyzed further if the total quantity of volatile and nonvolatile organic emissions (the sum of the TCO emissions and the gravimetric components) was less than 500 $\mu g/m^3$.

In the second stage of analysis, those samples with organic emissions greater than 500 $\mu g/m^3$ were fractionated by LC. (The LC method used provides some separation of components according to polarity.) The fractions were analyzed by the gravimetric and IR methods described previously. If the unfractionated sample contained more than 10 percent volatile organic material, fractions 1 through 7 were also analyzed for TCO components. Fractions which 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 which 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. Finally, aliquots from each sample concentrate were analyzed by GC/MS for POM.

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 either a saturated solution of sodium bicarbonate or ammonium chloride. The sample was extracted three times with a volume of high-purity methylene chloride equal to approximately 5 percent of the sample volume. The volume of the resulting extract was measured and concentrated.

- Extraction of Solid Samples -- The particulate filters 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 and concentrated.

- K-D Concentration -- 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.

All 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.

- IR 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.

- TCO Analysis -- GC was used to determine the quantity of low boiling hydrocarbons (BP between 100 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). Whenever the TCO concentration exceeded 75 $\mu g/m^3$, further GC analysis was conducted to determine the amount of individual species.

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

- LC Separation -- This procedure was designed to separate samples into eight reasonably distinct classes of compounds and was applied to all organic samples which 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 employed to separate the sample into eight fractions for further analyses. As 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 8) 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 in excess of 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.

- LRMS -- 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 which may be generally considered toxic; e.g., aromatic hydrocarbons and chlorinated organics. Analysis using different sample ionizing parameters results in molecular weight data which, 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 mixture. This is because of 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 via 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.

- GC/MS 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. This technique is classified as a Level II procedure.

  Microliter sized samples are injected onto a GC 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 via an instrument interface to the MS, 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. All compounds eluting from the GC in detectable quantities could be identified, including aromatic compounds containing heteroatoms, depending upon the desired scope of the analysis. The computer was used to search the stored spectra for the specific mass fragments shown in Table 17.

TABLE 17. MASS TO CHARGE VALUES MONITORED, m/e

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

*Internal Standard - Chloronaphthalene.

The spectra of POM's are quite distinctive because they yield very strong molecular ions with little fragmentation. Using molecular ions to find POM's 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 as well as the spectrum is 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's 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 18 lists POM's which are sought in all samples; any POM with a molecular weight on this list will be determined. If other POM's 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. The compounds listed in Table 18 represent essentially all POM compounds within the molecular weight range of 128 to 302. Many of these compounds have been identified from previous studies of combustion sources.

TABLE 18. MINIMUM LIST OF POM's MONITORED

Compound name	Molecular weight
Naphthalene	128
Biphenyl	154
Benzindene	166
Fluorene	166
Phenanthrene	178
Anthracene	178
Benzoquinoline	179
Acridine	179
9,10-dihydro-phenanthrene	180
9,10-dihydro-anthracene	180
1-Methyl-fluorene	180
2-Methyl-fluorene	180
9-Methyl-fluorene	180
2-Methyl-phenanthrene	192
3-Methyl-phenanthrene	192
2-Methyl-anthracene	192
Fluoranthene	202
Pyrene	202
Benzo(a)fluorene (1,2-benzofluorene)	216
Benzo(b)fluorene (2,3-benzofluorene)	216
Benzo(c)fluorene (3,4-benzofluorene)	216
2-Methyl-fluoranthene	216
1-Methyl-pyrene	216
3-Methyl-pyrene	216
4-Methyl-pyrene	216

(continued)

TABLE 18 (continued).

Compound name	Molecular weight
Benzo(c)phenanthrene	228
Benzo(ghi)fluoranthene	228
Benzo(a)anthracene	228
Chrysene (Benzo(a)phenanthrene)	228
Triphenylene (9,10-Benzophenanthrene)	228
4-Methyl-benzo(a)anthracene	242
1-Methyl-chrysene	242
6-Methyl-chrysene	242
Benzo(b)fluoranthene	252
Benzo(f)fluoranthene	252
Benzo(k)fluoranthene	252
Benzo(a)pyrene	252
Benzo(e)pyrene	252
Perylene	252
7,12-Dimethyl-benzo(a)anthracene	256
9,10-Dimethyl-benzo(a)anthracene	256
Benzo(c)tetraphene	256
1,2,3,4-Dibenzanthracene	278
2,3,6,7-Dibenzanthracene	278
Benzo(b)chrysene	278
Picene (3,4-Benzochrysene)	278
Coronene	300
Benzo(ghi)perylene	302
1,2,3,4-Dibenzpyrene	302
1,2,4,5-Dibenzpyrene	302

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, kept these interferences to a minimum. If a POM was confirmed, the peak was quantified using an internal standardization method.

The GC/MS sensitivity varies with several parameters, including the type of compound, internal instrument cleanliness, resolution of closely eluting peaks, etc. Under "everyday" operating conditions, 20 nanograms (ng) eluting in a peak about 5 seconds wide yields 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.

4.2.4 Test Results

4.2.4.1 Field Measurements and Emissions of Criteria Pollutants and SO_2, SO_3, and Particulate Sulfate--

Field data for all units tested are shown in Tables 19 and 20. Measurements of gaseous (boiling below 100°C) hydrocarbon, also made in the field, are reported later with the emission data for volatile (100 to 300°C BP range) and nonvolatile (BP greater than 300°C) organics measured in the laboratory.

Combustion parameter data are shown for two locations: at the stack exit where emissions were sampled, and at the location near the exit from the furnace. The gas composition data at the furnace exit location were obtained during the second test period to assess the operating condition of the units tested. Excess air levels at the furnace exit, as determined from CO_2 and O_2 measurements, ranged from 50 to 175 percent for the gas-fired units and from 50 to 150 percent for the oil-fired units. Normal excess air values are reportedly 20 to 500 percent and 10 to 100 percent for gas- and oil-fired systems, respectively.[8] Two of the gas-fired units, sites 127 and 129, show exceptionally high CO emission levels; and one oil-fired unit, site 326, also shows much higher than normal CO concentrations. Generally, CO levels of the magnitude measured would indicate highly inefficient combustion and lead to heavy soot formation and hydrocarbon emission levels significantly higher than those measured at these sites. Thus, the CO measurements at these sites appear invalid.

TABLE 19. FIELD DATA: GAS-FIRED RESIDENTIAL COMBUSTION SOURCES

Unit No.	Test No.	Cycle, on/off	Date of test	Rated input (10^6 J/hr)	CO_2 (%)	O_2 (%)	CO (ppmv)[*]	Particulate emissions		NO_x emissions		Bacharach smoke number
								(mg/m^3)	(ng/J)	(ppmv)[*]	(ng/J)	
1	100	50/10	6/10/77	85	6.4	16.7	ND	0.46	0.55	53	31	-
1	127[†]	-	3/13/78	85	9.3	9.7	1220	ND	ND	ND	ND	0-1
2	101	50/10	5/24/77	85	1.4	12.9	ND	0.40	0.26	11	6	-
2	128[†]	-	3/13/78	85	7.9	11.3	0	ND	ND	ND	ND	0-1
3	102	50/10	5/26/77	85	3.0	19.5	ND	0.49	1.7	119	66	-
3	125[†]	-	3/10/78	85	4.4	14.3	16	ND	ND	ND	ND	-
4	103	50/10	6/08/77	106	1.7	19.1	ND	0.64	1.7	66	33	-
4	126[†]	-	3/17/78	106	5.7	11.6	0	ND	ND	ND	ND	0-1
5	104	50/10	6/14/77	79	1.1	16.8	ND	0.62	0.76	21	11	-
6	129[†]	-	3/13/78	85	5.4	10.5	920	ND	ND	ND	ND	1
6	130	50/10	3/14/78	85	4.1	15.8	ND	ND	ND	ND	ND	-
6	131	10/20	3/15/78	85	3.5	14.3	ND	ND	ND	ND	ND	-

[*] ppmv values at 3 percent O_2.

[†] Parameter check at exit from heat exchanger; other tests at stack exit.

ND - Not Determined.

TABLE 20. FIELD DATA: OIL-FIRED RESIDENTIAL COMBUSTION SOURCES

Unit No.	Test No.	Cycle, on/off	Date of test	Rated input (10^6 J/hr)	CO_2 (%)	O_2 (%)	CO (ppmv)*	Particulate emissions		Bacharach smoke number
								(mg/m^3)	(ng/J)	
1	300	50/10	5/18/77	192	3.8	17.2 ✓	ND	2.3	3.1	-
1	300-2†	-	4/24/78	192	6.5	14.3	40	ND	ND	1
2	301	50/10	5/24/77	185	3.7	17.4 ✓	ND	1.2	1.7	-
2	301-2†	-	4/19/78	185	7.2	11.4	< 18	ND	ND	1
3	302	50/10	5/27/77	83	1.2	19.6	ND	2.2	8.3	-
3	302-2†	-	4/17/78	83	7.3	14.6	8	ND	ND	1
4	303	50/10	6/02/77	118	2.9	17.3	ND	2.5	3.5	-
4	303-2†	-	4/18/78	118	10.4	7.5	< 2	ND	ND	1
5	304	50/10	6/29/77	92	2.6	17.5	ND	1.9	2.8	-
6	326-1	50/10	5/23/78	149	3.1	14.5	620	1.7	1.3	2
6	326-2	10/20	5/24/78	149	6.6	13.9	565	1.6	1.3	2
7	327-1	10/20	5/31/78	127	8.3	12.8	< 2	1.9	1.2	1
7	327-2	50/10	6/02/78	127	1.5	15.0	< 3	1.5	1.3	1

*ppmv values at 3 percent O_2.

†Parameter check at exit from heat exchanger; other tests at stack exit.

ND - Not Determined.

As discussed previously in section 4.1, the existing data base was found to be adequate for SO_2, NO_x, and CO emissions for both gas- and oil-fired residential heating sources. Additional SO_2, NO_x, and CO measurements were, therefore, unnecessary for the construction of the emissions data base. Nevertheless, NO_x emissions were determined using a theta sensor for the five gas-fired units initially tested.

Particulate emissions from oil-fired units exceed those from gas-fired units. Further, cycle mode did not affect particulate emissions from the two oil-fired units tested. The average NO_x emission factor of 33 ng/J for the five gas-fired systems is identical to the EPA emission factor. SO_2 emissions, although not measured, would be equivalent to 106 ng/J for the oil-fired sites, based on an average fuel sulfur content of 0.24 percent. The emission factor for SO_2 from the gas-fired sources would be 0.26 ng/J, based on a sulfur content of 4600 $g/10^6\ Nm^3$.

Sulfur component analyses of oil-fired sites 326 and 327, obtained using the Goksöyr-Ross sampling train and Level II analysis, determined that an average of 95 percent of fuel sulfur was emitted as SO_2, 4.4 percent as SO_3, and 0.55 percent as particulate sulfate. SO_3 conversions measured were 6.5 and 4.5 percent for the two tests at site 326 and 2.1 and 4.4 percent for the two tests at site 327. The SO_3 emissions are greater than those normally encountered in larger combustion systems (1 to 3 percent), but similar results have been noted in other studies.[19,20] Experimental error due to overtitration was proposed as the reason for the apparently high SO_3 concentrations observed for low sulfur fuel oils.[19] The analytical procedure used in this study differed from that used by KVB[19] and does not appear to be the cause of the higher than expected SO_3 emissions. However, the results appear to be within the normal range of values found by Goksöyr-Ross analysis of SO_3 emissions from combustion sources.[20] Further study will be needed to determine if the high SO_3 emissions are a result of normal analytical data scatter or are a real effect resulting from high excess air levels.

The data reduction procedures for converting emission concentrations (ppmv or mg/m^3) to emission factors (ng/J) are based on calculation of the combustion of fuel with air, as described in detail in Appendix E.

4.2.4.2 Inorganic Analysis Results--

Trace element data, obtained by SSMS analysis, are contained in Appendix F in 11 tables. Tables F-1 to F-5 contain the results from the gas-fired sites; Tables F-6 to F-11 provide results from the oil-fired sites. 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 to calculate emissions. However, in the case of the oil-fired sites, the fuel was also analyzed. Based on the assumption that the total elemental content of the fuel is emitted with the flue gas, mass emissions for these sites were determined from the fuel analytical results.

Trace element emissions from the gas-fired sites were low. Only about 25 elements were positively detected. With the exception of two obvious outliers; i.e., Si in site 100 and Cu in site 102, all identified trace element emission levels were less than 0.025 mg/m^3.

Trace element emissions from the oil-fired sites were greater than those from the gas-fired sites. Several elements (Al, Ca, Mg, Ni, K, and Na) were emitted in quantities ranging from 0.1 to 0.45 mg/m^3, based on the fuel content analysis by SSMS. Emissions were calculated using the methods shown in Appendix E.

A summary of the data for specific inorganic analyses for mercury, arsenic, and antimony, as determined by AAS, is given in Table 21. Arsenic and antimony emissions were also calculated from the results of SSMS analysis. Arsenic emission values determined by SSMS were roughly a factor of five higher than those obtained by AAS for the oil-fired sites. Antimony values were in reasonable agreement; however, mass emissions of all three elements as measured by AAS are quite low.

4.2.4.3 Organic Analysis Results--

Total Organic Matter--A summary of the organic analyses is presented in Table 22. As noted previously, the GC determination of hydrocarbons boiling in the same range as methane (C_1) through n-hexane (C_6) was done in the field while the analysis of hydrocarbons boiling in the range of n-heptane (C_7)

TABLE 21. SUMMARY OF AAS RESULTS FOR Hg, As, AND Sb

Combustion source type	Site No.	Mass emissions (mg/m^3)		
		Hg	As	Sb
Gas-fired	100	0.00003	< 0.0002	< 0.0007
	101	0.00025	0.0004	< 0.0009
	102	0.003	< 0.0002	0.004
	103	0.004	< 0.0002	< 0.0007
	104	0.001	< 0.0002	< 0.0007
Average		0.0076	< 0.00025	< 0.0014
Oil-fired	300	0.0007	< 0.00025	< 0.0015
	301	< 0.0008	< 0.00025	0.0017
	302	< 0.0008	< 0.0001	< 0.0016
	303	< 0.0008	< 0.00025	< 0.002
	304	< 0.0005	< 0.00025	0.0033
Average		< 0.00072	< 0.00022	< 0.002

TABLE 22. TOTAL ORGANIC EMISSIONS FROM GAS- AND OIL-FIRED RESIDENTIAL COMBUSTION SOURCES

	Gas-fired sources							Oil-fired sources								
	100	101	102	103*	104	130	131†	300	301	302	303	304	326-1	326-2†	327-1†	327-2
Volatile Organics Analyzed in Field (μg/m³)																
C_1	LD	LD	LD	39,400	LD	LD	LD	9600	9720	2000	1800	2800	LD	LD	LD	LD
C_2	LD	LD	LD	37,800	LD	LD	LD	1700	1900	400	LD	140	LD	LD	LD	LD
C_3	LD	LD	LD	5,500	LD	LD	LD	LD	4400	LD	LD	LD	LD	LD	LD	LD
C_4	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD
C_5	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD
C_6	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD
Volatile Organics Analyzed in Laboratory (μg/m³)																
C_7 (BP 90-110°C)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C_8 (BP 110-140°C)	< 10	< 10	ND	< 10	< 10	ND	ND	6	1	8	1	5	ND	ND	ND	ND
C_9 (BP 140-160°C)	< 10	< 10	ND	< 10	< 10	ND	ND	5	3	9	15	7	ND	ND	ND	ND
C_{10} (BP 160-180°C)	1490	< 10	ND	770	1960	ND	ND	46	14	26	43	43	ND	ND	ND	ND
C_{11} (BP 180-200°C)	560	< 10	ND	600	2680	ND	ND	25	7	44	47	49	ND	ND	ND	ND
C_{12} (BP 200-220°C)	60	< 10	ND	< 10	370	ND	ND	1	33	45	65	81	ND	ND	ND	ND
C_{13} (BP 220-240°C)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C_{14} (BP 240-260°C)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C_{15} (BP 260-280°C)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C_{16} (BP 280-300°C)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C_7-C_{16} (BP 90-300°C)	ND	ND	ND	ND	ND	117	140	170	180	560	560	320	260	610	385	235
Nonvolatile Organics Analyzed in Laboratory (μg/m³)																
> C_{16} (BP > 300°C)	400	1240	780	480	920	340	304	650	1800	420	1300	1210	1900	1200	370	620
Total Organics (mg/m³)	2.5	1.2	0.8	1.9	5.9	0.5	0.4	12.1	11.0	2.8	3.7	9.3	2.2	1.8	0.7	0.9

*C_1-C_6 values not included in total.

†10/20 cycle; all other tests 50/10 cycle.

LD - Lower than detection limit: 100 to 1000 μg/m³ for C_1-C_6; 1 μg/m³ for C_7-C_{16}.

ND - Not determined.

through n-hexadecane (C_{16}) was performed in the laboratory.* The sensitivity of the GC in the laboratory is about a thousand times greater than the sensitivity of the instrument taken into the field. The corresponding limit of detection for the field GC is about 100 to 1000 μg hydrocarbon/m^3, whereas the laboratory GC can detect 1 $\mu g/m^3$. This is the principal reason for the limited data in Table 22 for C_1 through C_6 organics measured in the field. The nonvolatile organic content of the samples was also determined in the laboratory, using the procedure for gravimetric analysis.

There is a large variation in the C_1 to C_6 concentrations found in the oil-fired systems. Sites 300 to 304 all show the presence of C_1 to C_3 organics. Only one gas-fired site (103) contained C_1 to C_3 organics in excess of the GC detection limit. An examination of this site revealed a defective unit, and the large values reported in Table 22 for C_1 to C_3 from site 103 are a result of this defect. The emission levels detected should not be considered representative of gas-fired sources and are not included in subsequently determined emission rates.

The concentration of materials boiling between 110 and 220°C (C_8 to C_{12}) varied from < 10 to 5000 $\mu g/m^3$ in the samples from the gas-fired sources and from 60 to 185 $\mu g/m^3$ in the samples from the oil-fired sources. The nonvolatile organics (> C_{16}) from the gas-fired sites showed less variability than the volatile fraction, ranging from 300 to 1240 $\mu g/m^3$. The variability of nonvolatile emissions from the oil-fired sites was within reasonable limits; 370 to 1900 $\mu g/m^3$.

The organic content of SASS train samples from the gas-fired sites averaged 1880 $\mu g/m^3$, while the average from the oil-fired sites was 1430 $\mu g/m^3$. Total organics, however, were greater on the average for the oil-fired sources (4.9 mg/m^3) than those measured for the gas-fired sources (1.9 mg/m^3), due to higher gas phase organic emissions from the oil-fired sources.

Nonvolatile organics from both gas- and oil-fired units were found on the walls of the XAD-2 resin module as well as in the resin, in contrast to the

---

*For the initial five gas-fired and five oil-fired residential sources, the laboratory GC procedure measured only C_8, C_9, C_{10}, C_{11}, and C_{12} individually, and total C_7 through C_{16}.

volatile components which were collected almost entirely by the resin. Further details on the distribution of organics collected by the SASS train are given in Appendix F, Tables F-12 through F-15.

Total organic emissions as measured did not show a dependence upon cycle mode. This result is in contrast to findings of other investigations and is discussed in the section on Analysis of Test Results.

Organic Component Analysis--Further characterizations were conducted on SASS samples containing high levels of organic material. Because most of the organics were found in the XAD-2 resin sample and in the condensate and module rinse combination sample, these samples were subjected, as required by the analysis strategy, to LC fractionation with subsequent volatile and nonvolatile mass determinations and IR analyses of the LC fractions.

LC fractionation--For gas-fired sources, SASS components which contained > 240 $\mu g/m^3$ of nonvolatile organics were analyzed by LC fractionation. Table 23 shows the results of gravimetric analysis of the resulting LC fractions. All XAD-2 resin samples from the oil-fired sources were fractionated, and the results of both TCO and gravimetric analyses of the fractions are also shown in Table 23. (An explanation of the sample identification codes is given in Figure 9.) There is no definite trend as to the quantity of organics contained in the LC fractions. Aliphatic and aromatic hydrocarbons are eluted in fraction 1; while fractions 5, 6, and 7 contain such polar species as esters and other carboxylic acid derivatives, aldehydes and ketones, phenolics and amines.

IR analysis--IR analyses were not conducted on the gas-fired SASS train samples because of phthalate ester contamination from plastic components used throughout the laboratory. Corrective measures have since been successful in eliminating this source of interference. While no data are available, a general interpretation of the LC fraction gravimetric data (Table 23) can be made by comparison with the theoretical types of compounds which are usually present in LC fractions.[1]

An interpretation of IR spectra obtained from the LC fractions of the XAD-2 resin extracts from the oil-fired sites is shown in Table 24. The classes of compounds identified apply only to the nonvolatile (> C_{16}) portion

TABLE 23. ORGANIC ANALYSIS RESULTS OF LC FRACTIONATION OF SASS SAMPLES FROM GAS- AND OIL-FIRED RESIDENTIAL SOURCES, μg/m^3

Source category	Site No.	Sample code	Analysis	LC-1	LC-2	LC-3	LC-4	LC-5	LC-6	LC-7	Total
Gas-fired	101	XR	Grav	150	66	23	18	2	87	44	391
		CDMR	Grav	< 0.8	< 0.8	12	430	110	120	140	815
	102	XR	Grav	110	< 0.4	38	23	76	110	< 0.4	350
		CDMR	Grav	< 0.5	< 0.5	< 0.5	280	100	72	16	474
	103	CDMR	Grav	< 0.8	100	61	520	< 0.8	< 0.8	150	843
Oil-fired	300	XR	TCO	43	36	17	15	17	45	< 0.2	173
			Grav	88	< 0.5	< 0.5	24	107	91	157	467
			Total	131	36	17	39	124	136	157	640
	301	XR	TCO	68	16	15	20	36	14	9	165
			Grav	30	23	35	15	23	402	65	593
			Total	98	39	50	35	59	416	74	758
	302	XR	TCO	91	62	48	84	179	101	< 0.6	565
			Grav	1	2	6	4	10	17	250	290
			Total	92	64	54	88	189	118	250	855
	303	XR	TCO	< 0.5	10	84	135	155	144	29	557
			Grav	266	40	288	152	152	342	19	1059
			Total	266	50	372	287	307	486	48	1616
	304	XR	TCO	250	27	23	19	5	4	-	328
			Grav	2250	140	280	400	280	730	400	4480
			Total	2500	167	303	419	285	734	400	4808

XXX-XX-XX-XX

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:

FF - Fuel feed (oil)
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
AI - APS impingers
PF - Particulate filter(s)
1C - 1-3μ cyclone
FC - PF plus 1C
3C - 3-10μ cyclone
10C - > 10μ cyclone
CC - 3C plus 10C

SAMPLE PREPARATION

Codes and corresponding preparation steps are as follows:

0 - 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

GC - C_7-C_{16} GC
GI - Grav., IR
GM - GC/MS
LC - LC separation

Second Level

Resulting LC fractions are numbered in order 1-7 for:

GC - C_7-C_{16} GC
GI - Grav., IR
MS - LRMS

Figure 9. Sample identification and coding for residential sources.

TABLE 24. CLASSES OF COMPOUNDS IDENTIFIED IN IR SPECTRA OF XAD-2 RESIN LC FRACTIONS FROM OIL-FIRED RESIDENTIAL SOURCES

Site	LC-1	LC-2	LC-3	LC-4	LC-5	LC-6	LC-7
300	Alkanes	-	-	Substituted aliphatics; R-CN	Substituted aliphatics and ethers	Substituted aliphatics and alcohols	Substituted aliphatics, carboxylic acids
301	Aliphatics	Aliphatics and halogen substituted aliphatics	Substituted aliphatics	Substituted aliphatics	Substituted aliphatics	Aliphatics and/or aromatic esters, ketones and phenols	Aliphatic acids
303	Aliphatics	Substituted aliphatics	Substituted aliphatics, ethers, esters and ketones	Substituted aliphatics, ethers, esters and ketones	Ethers, esters and ketones	Ethers, esters and ketones	Aliphatic acids
304	Aliphatics and aromatics	Aliphatics and aromatics	Substituted aliphatics, ethers, esters and ketones	Substituted aliphatics, ethers, esters and ketones	Carbonyl compounds and aromatics	Carbonyl compounds and aromatics	Substituted aromatics, aliphatics, carboxylic acids
327-1	Aliphatics and aryl ketones	Aliphatics	Aliphatics	Esters and ketones	Esters and ketones	Esters, ketones; possible ethers, carboxylic acids, alcohols and phenols	Carboxylic acids, alcohols and phenols
327-2	Aliphatics	Aliphatics	Aliphatics	Unsaturated or aryl esters and ethers	Unsaturated or aryl esters and ethers	Esters, ketones, amides, amines, alcohols and phenols	Unsaturated or aryl esters

of the LC fractions. The IR spectra were obtained on a spectrophotometer which, although in conformance with Level I requirements, was insufficiently sensitive to allow detailed evaluation of the classes of compounds present.

GC/MS Analysis for POM--For the gas-fired sources, only the XAD-2 resin extracts contained amounts of POM's which exceeded the detection limits of the analysis (0.3 $\mu g/m^3$). Naphthalene was found in resin samples from sites 100 and 102 and its source is believed to be the result of leaching of material from the XAD-2 resin.

The results of the GC/MS analyses for POM's from the oil-fired sources are given in Table 25. Compounds not listed or for which no values are listed were below the detection limit. As expected, most of the detectable POM's were found in the XAD-2 resin samples, and the compounds found were relatively low molecular weight species. The compounds detected were not particularly hazardous. The most hazardous POM constituents; e.g., benzo(a)-pyrene and benzo(a)anthracene, were not detected. Cycle mode did not have a measurable effect on POM emissions.

4.3 ANALYSIS OF EXISTING DATA AND TEST RESULTS

4.3.1 Emissions of Criteria Pollutants and SO_2, SO_3, and Particulate Sulfate

The particulate, NO_x, and total organic emission factor data resulting from this emissions assessment program for gas- and oil-fired residential combustion sources are presented in Table 26. As shown in this table, data variability is large for both the gas- and oil-fired systems for all pollutants, reflecting the inherent variability in emissions from residential sources and the semiquantitative nature of Level I analysis.

A comparison of the new data with existing data and EPA emission factors[3] is presented in Table 27. For the gas-fired units, the measured particulate emission is over twice as large as that given in the literature but only one-half that of the emission factor obtained by Battelle.[2] The Battelle data were used by EPA to modify its emission factor values for many of the criteria pollutants emitted by gas-fired residential systems. The measured emission factor for NO_x is identical to EPA's value. The organic emission factor

TABLE 25. POM EMISSIONS FROM OIL-FIRED RESIDENTIAL SOURCES,* µg/m^3

Compound	Site 301		Site 302		Site 303	Site 304		Site 327-1†	Site 327-2
	Module rinse	XAD-2 resin	Module rinse	XAD-2 resin	XAD-2 resin	Conden-sate	XAD-2 resin	‡	‡
Acenaphthene		9.3							
Acetonaphthone		2.3					0.5		
Anthracene					1.5				
Azulene or naphthalene		20						6	4
Benzo(c)cinnoline		1.2							
Biphenyl		23		1.0				1.1	
Butyl phenanthrene							20		
Dimethyl naphthalene				6.0	2.5			0.2	
Dimethyl phenanthrene				0.4					
Ethyl naphthalene		23					6.5		
Fluorenone	4.2§	4.7				0.7			
Methyl anthracene		2.4							
Methyl dibenzo thiophene				0.1					
Methyl naphthalene					7.6		15.4	1.1	0.6
Methyl phenanthrene				0.2					
Octyl phenanthrene							3.7		
Phenanthrene	0.5	4.7	0.1	3.0		1.7			
Phenanthrene quinone	4.2§	1.2	0.1						

---

*Compounds not listed were below the detection limit of ~0.3 µg/m^3. No POM compounds were detected in other SASS fractions.

†10/20 cycle; all other tests 50/10 cycle.

‡Combined sample of XAD-2 resin and particulate filter extracts and solvent module and probe rinses.

§Fluorenone or phenanthrene quinone.

TABLE 26. MEASURED EMISSION FACTORS FOR PARTICULATE, NO_x, AND TOTAL ORGANICS

Combustion source type	Site No.	Pollutant (ng/J)		
		Particulate	NO_x	Total organics
Gas-fired sources	100	0.55	28	3.0
	101	0.26	6	1.5
	102	1.7	66	0.9
	103	1.7	53	2.3
	104	0.76	12	7.1
	130	ND	ND	0.5
	Mean $\overline{x}$	0.99	33	2.55
	$s(\overline{x})$	0.30	11.58	0.98
	$ts(\overline{x})/\overline{x}$	0.83	0.97	0.99
Oil-fired sources	300	3.1	ND	16.2
	301	1.7	ND	15.4
	302	8.3	ND	11.7
	303	3.5	ND	5.1
	304	2.8	ND	13.4
	326-1	1.3	ND	1.7
	327-2	1.3	ND	0.7
	Mean $\overline{x}$	3.1	-	9.2
	$s(\overline{x})$	0.92	-	2.47
	$ts(\overline{x})/\overline{x}$	0.72	-	0.66

ND - Not Determined.

Note: $\overline{x}$ - Mean, ng/J

$s(\overline{x})$ - Standard error, ng/J

$ts(\overline{x})/\overline{x}$ - Variability, percent/100

TABLE 27. COMPARISON OF CRITERIA POLLUTANT EMISSION FACTORS FOR GAS- AND OIL-FIRED RESIDENTIAL COMBUSTION SOURCES

Combustion source type	Data source*	Pollutant (ng/J)				
		Particulate	NO_x	SO_2	CO	HC
Gas-fired sources	Test program	1.0	33	ND	ND	2.6
	Existing data	0.4	57	0.21	38	39
	Existing data[2]	2.1	36	-	8	2.0
	EPA AP-42[3]	2 - 6	33	0.26	8.4	3.3
Oil-fired sources	Test program	3.1	ND	ND	ND	9.2
	Existing data	8	44	93	47†	10†
	EPA AP-42[3]	7.7	55	106	15	3

---

*The existing data base is discussed in Section 4.1.

†Includes tests with excessively high HC and CO values; if these data are not included, HC and CO values are reduced to 2 and 17, respectively.

ND - Not Determined.

2.5 lb/10³ gal for part

NOx

[illegible] AP-42

18

obtained in this program is only slightly less than the published EPA value but well below the average value obtained from the existing literature.

For the oil-fired sources, the measured emission factor for filterable particulates is less than half of the emission factor obtained by Battelle[2] and adopted by EPA.[3] The total organic emission factor is comparable to the existing data base but three times greater than the published EPA emission factor. It should be noted that the existing data base value is highly biased by the presence of two extremely high readings (see Appendix D). If these outliers are omitted from the data base, as was done by EPA in arriving at its emission factor, the existing data emission factor drops from 10 to about 2 ng/J. The higher value obtained in this test program probably is a result of experimental procedures. The total hydrocarbon emission data determined by previous investigations were obtained using gas chromatography with flame ionization detection, and some of the heavier hydrocarbons may have condensed in the sampling lines and, therefore, were not measured.

Data for the 10/20 duty cycle tests are not included in Tables 26 and 27. Particulate emissions from the oil-fired sites, as measured for the 10/20 duty cycle, were identical to the 50/10 duty cycle emissions. Organic and POM emissions from both the gas- and oil-fired sites were also essentially unaffected by duty cycle. This is in contrast to an earlier study[2] which indicates that organic emissions decrease when the percent "on" time is increased. For example, a decrease in emissions of roughly 20 percent was found when the percent "on" time was doubled for a 15-minute total on/off duty cycle. The difference is attributed to combustion temperature considerations and is dependent in part upon the temperature response time of the combustion chamber. The failure to detect any change in organic emissions in this study is probably due to the inherent accuracy limitations of the Level I measurements and analyses.

Emission factors for CO and SO_2 are available in the existing data base. SO_2 emission factors published by EPA and shown in Table 27 are based on a fuel sulfur content of 4,600 $g/10^6\ m^3$ for gas and 0.24 percent for oil. CO emission factors in the existing literature are much higher than the EPA values and reflect, in part, the contribution of outliers in the existing data base. If these outliers are discarded, the emission factor drops to about 17 ng/J. CO emission factors for approximately 6 percent of gas-fired units[13,14] and 10 percent of oil-fired units[2,11,12] in the existing data base were in excess of 100 ng/J in the as-found condition. The high CO emissions are due to poorly functioning units. These same units contributed to the high hydrocarbon emission factor noted in the existing data base.

Data on the composition of SO_x from combustion sources indicate that 90 to 100 percent of the emitted SO_x is SO_2. The remaining fraction of SO_x emission is SO_3 and its derivatives. The main SO_3 derivative is sulfuric acid; metallic sulfates appear to be directly emitted only in trace quantities. The Goksöyr-Ross train, described previously, was used at sites 326 and 327 to measure SO_2, SO_3, and particulate sulfate. The percent conversion of sulfur to particulate sulfate averaged 0.55 percent, based on the results of two tests at each site. The average measured conversion of sulfur to SO_3 of 4.4 percent was higher than anticipated, since values of 1 to 3 percent have been reported generally for larger combustion systems. However, as noted previously, high conversions have been obtained in previous studies.[19,20] In certain cases, these high conversions have been attributed to errors in the chemical analyses of the combustion products of low sulfur fuels. However, the resolution of these observations will require further study to determine if the high SO_3 emissions from residential sources are real or are the result of experimental data scatter.

The significance of the emissions of criteria pollutants and SO_3 from gas- and oil-fired residential combustion sources can be assessed using the source severity factor. The source severity factor has been discussed briefly in section 4.1, and detailed methods for the calculation of single source severity factors are described in Appendix C. Basically, the source 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. Source severity factors below 0.05 are deemed insignificant. In the case of residential sources, the multiple source severity factor is used to indicate the potential environmental significance of emissions.

Multiple source severity factors were determined by using a standard dispersion technique and a residential area of 1,000 residential units. The model assumes a class C stability (slightly unstable) and windspeed of 4.5 m/sec (10 mph). Using a grid of houses 80 × 80 m and the average stack parameters found in this study, the dilution was equivalent to a factor of 3,200. The multiple source severity factors calculated from the ambient concentrations determined by the model are 25 times greater than single source severity factors.

As shown in Table 28, multiple source severity factors exceed 0.05 for several pollutants: NO_x from gas-fired sources and SO_3 and NO_x from oil-fired sources. A potential hazard is associated with these pollutants, given the multiple array of sources and the meteorological condition used in this study for the modeling of ambient concentrations.

4.3.2 Emissions of Trace Elements

Existing trace element data for gas- and oil-fired residential combustion sources are inadequate. During this program, trace element emissions were measured by SSMS for several elements and by AAS for Hg, As, and Sb. The trace element content of the oil was also determined and potential emissions calculated assuming complete release to the atmosphere. In almost all cases, the measured stack emissions were lower by a factor of roughly two than those calculated from the fuel analysis (see Appendix F).

Trace element concentrations as determined by SSMS for the gas-fired sources were lower than those determined for the oil-fired sites. Emissions from gas-fired sources either were not detectable or were lower than blank values for over 90 percent of the elements. Trace element emissions from gas-fired sources are not an environmental hazard.

Trace element emission factors for the oil-fired sources are presented in Table 29. Elements shown are those that are present in appreciable quantities plus some elements which have low TLV values. The upper bound emissions were calculated from analysis of the oil, thus representing the worst case condition. Data variability, also shown in Table 29, is greater than 0.7 for over 50 percent of the elements.

TABLE 28. CRITERIA POLLUTANT AND SO_3 SEVERITY FACTORS FOR RESIDENTIAL SOURCES

Pollutant	Gas-fired sources			Oil-fired sources		
	Emissions* (ng/J)	Severity factor	Multiple source severity factor	Emissions* (ng/J)	Severity factor	Multiple source severity factor
Particulate	1.0	1.7×10^{-5}	4.3×10^{-4}	3.1	7.7×10^{-5}	1.9×10^{-3}
SO_2	0.26	3.2×10^{-6}	8.0×10^{-5}	106	1.9×10^{-3}	4.8×10^{-2}
SO_3	ND	ND	ND	5.9	1.6×10^{-2}	4.0×10^{-1}
NO_x	33	2.8×10^{-3}	7.0×10^{-2}	55	6.2×10^{-3}	1.6×10^{-1}
CO	8.4	1.6×10^{-6}	4.0×10^{-5}	15	4.2×10^{-6}	1.1×10^{-4}
Organics (total)	2.6	1.0×10^{-4}	2.5×10^{-3}	9.2	5.3×10^{-4}	1.3×10^{-2}

*SO_2 and CO emissions from gas-fired sources and SO_2, NO_x, and CO emissions from oil-fired sources were not measured. EPA emission factors[3] were used to calculate source severities for these pollutants.

ND - Not Determined.

TABLE 29. TRACE ELEMENT EMISSION FACTORS FOR OIL-FIRED RESIDENTIAL SOURCES, ng/J

Element	$\overline{x}$	$ts(\overline{x})/\overline{x}$	$\overline{x}_u$
Pb	0.042	0.81	0.075
Ba	0.016	0.61	0.026
Sb	0.0057	1.32	0.0013
Cd	0.011	0.97	0.022
As	0.0015	1.17	0.003
Zn	0.11	0.41	0.16
Cu	0.16	0.59	0.25
Ni	0.29	0.65	0.49
Fe	0.14	5.62	0.92
Cr	0.029	0.95	0.055
V	0.0029	1.21	0.006
Ca	0.45	0.56	0.71
K	0.23	0.96	0.45
Al	0.25	0.69	0.42
Mg	0.21	1.1	0.44
Hg*	0.0012	-	-

*Determined by AAS; all others by SSMS.

Note: $\overline{x}$ - Mean

$ts(\overline{x})/\overline{x}$ - Variability, percent/100

$\overline{x}_u$ - Upper bound of mean

Multiple and single source severity factors for trace elements are shown in Table 30 for the oil-fired sites. Only Ni with a multiple source severity factor of 0.25 exceeds the value of 0.05, thus representing a potential environmental hazard.

TABLE 30. TRACE ELEMENT SEVERITY FACTORS FOR OIL-FIRED RESIDENTIAL SOURCES

Element	TLV ($\mu g/m^3$)	Maximum severity factor	Multiple source severity factor
Pb	150	1.0×10^{-3}	17×10^{-3}
Ba	500	0.11×10^{-3}	2.8×10^{-3}
Sb	500	0.05×10^{-3}	1.3×10^{-3}
Cd	50	1.0×10^{-3}	23×10^{-3}
As	500	0.005×10^{-3}	0.1×10^{-3}
Zn	5,000	0.06×10^{-3}	2.0×10^{-3}
Cu	1,000	0.5×10^{-3}	12×10^{-3}
Ni	100	10×10^{-3}	250×10^{-3}
Fe	5,000	0.7×10^{-3}	10×10^{-3}
Cr	100	1.0×10^{-3}	25×10^{-3}
V	500	0.03×10^{-3}	0.8×10^{-3}
Ca	5,000	0.3×10^{-3}	7.4×10^{-3}
K	2,000	0.47×10^{-3}	12×10^{-3}
Al	10,000	0.09×10^{-3}	2.3×10^{-3}
Mg	10,000	0.09×10^{-3}	2.3×10^{-3}
Hg*	50	0.05×10^{-3}	1.3×10^{-3}

*Determined by AAS; all others by SSMS.

4.3.3 Emissions of POM

Emissions of POM from gas-fired sites, with the exception of naphthalene, could not be differentiated from the blank values and are, therefore, considered insignificant. The naphthalene concentration observed was 10^4 orders of magnitude less than the MATE value.

The concentrations of POM's found in the flue gas from oil-fired residential sources were two to three orders of magnitude below published MATE values, as shown in Table 31. Multiple source severity factors, based on maximum measured concentrations, were small (10^{-3} to 10^{-7}). POM emissions are not significant from the gas- and oil-fired residential combustion sources tested in this program.

TABLE 31. POM EMISSIONS AND SEVERITY FACTORS FOR OIL-FIRED RESIDENTIAL SOURCES

Compound	Maximum measured stack concentration* ($\mu g/m^3$)	MATE value ($\mu g/m^3$)	Multiple source severity factor
Acenaphthene	9.3		
Acetonaphthone	2.3		
Anthracene	1.5	480	3.0×10^{-4}
Azulene or naphthalene	20	225,000	6.0×10^{-5}
Benzo(c)cinnoline	1.2		
Biphenyl	23	1,000	2×10^{-3}
Butyl phenanthrene	20		
Dimethyl naphthalene	6.0	225,000	1.5×10^{-5}
Dimethyl phenanthrene	0.4		
Ethyl naphthalene	23	225,000	6.5×10^{-5}
Fluorenone	8.9		
Methyl anthracene	2.4	480	4.5×10^{-4}
Methyl dibenzo thiophene	0.1	200,000	4×10^{-8}
Methyl naphthalene	15.4	225,000	4.5×10^{-5}
Methyl phenanthrene	0.2	30,000	7×10^{-7}
Octyl phenanthrene	3.7		
Phenanthrene	5.2	1,600	3.0×10^{-4}
Phenanthrene quinone	5.4		

*See Table 25 to identify sites of maximum emissions.

4.3.4 Summary of Status of Emissions Data Base

Based on the analysis of the program test results and the existing data base, the status of the emissions data base for gas- and oil-fired residential sources can be summarized as follows:

- Emissions of criteria pollutants are adequately characterized. There is no need for Level II or additional Level I tests.
- For oil-fired sources, the high SO_3 levels measured at the two sites tested indicate a potential environmental risk, although the high emission levels measured may be due to the analytical technique employed. Further work to resolve this uncertainty is indicated.
- Trace element data for the gas-fired sources are adequate.
- Trace element emission data are also adequate for oil-fired sources; only Ni is emitted in amounts which could be potentially significant. Because additional data for Ni and other trace elements may be obtained through an analysis of fuel samples, there is no need for further Level II or additional Level I tests.
- POM emissions, as measured from the sources tested in this program, do not constitute an environmental problem. However, because of the potential hazard associated with these compounds, additional testing appears warranted.
- No effect of cycle on/off mode (50 minutes on/10 minutes off versus 10 minutes on/20 minutes off) on emissions was found, as measured by Level I analysis. However, this conclusion is based on a very limited number of tests and is contrary to the results of earlier studies. Further work to determine the effect of cycle mode on emissions appears necessary. This work should also investigate in more detail than was possible in this program the effect of burner and furnace design parameters on emissions.

5. TOTAL EMISSIONS

Based on the results of this sampling and analysis program and the existing emissions data base, estimates of current national emissions and projected 1985 national emissions from gas- and oil-fired residential combustion sources for space heating have been made using recent and projected fuel consumption rates.

5.1 CURRENT AND FUTURE FUEL CONSUMPTION

During the year 1978, residential heating systems consumed 2550 × 10^{15} Joules (2400 × 10^{12} Btu) of oil and 3900 × 10^{15} Joules (3700 × 10^{12} Btu) of gas. These fuel consumption figures were derived using the methods discussed in Appendix B.

Consumption of gas and oil for residential space heating is predicted to decrease 2.9 percent and increase 3.5 percent, respectively, from 1978 to 1985. Emissions will increase almost proportionately, although the introduction of new burner and furnace designs and other factors will lead to some reduction of the projected values for most pollutants. NO_x emissions may increase slightly due to increased use of flame retention burners.

Prediction of fuel use trends from the present time to 1985 is subject to many uncertainties. Population growth, technology changes, economic growth (Gross National Product (GNP) and all sectors comprising the GNP), fuel unavailability, governmental regulations, and imported oil prices and availability which may be affected by political factors are a few of the parameters that need to be considered in developing a complete fuel use projection model. The Federal Energy Administration (FEA) completed a projection of fuel use trends in 1976 that included most of the factors mentioned above as well as additional factors.[21] Any complex projection is obviously beyond the scope of this project. Predictions of future energy trends are subject to radical changes from year to year. Therefore, estimates discussed in this report are based on two recent studies[21,22] and our interpretation of these studies and related data.

The U.S. Department of the Interior, Bureau of Mines (BOM), has published estimates of energy use trends to the years 1980, 1985, and 2000.[22] Their projections are "based essentially on the evaluation of Bureau of Mines fuels data" and the assumption that "existing patterns of resource utilization will continue."

BOM and FEA fuel projections for the combined residential/commercial sector for the year 1985 are presented in Table 32.

TABLE 32. CONSUMPTION OF ENERGY IN THE RESIDENTIAL AND COMMERCIAL SECTOR, 1974, AND PROJECTIONS TO 1985, 10^{15} Joules

Energy source	BOM[22]			FEA[21]		
	1974	1985	Percent change from 1974	1974	1985	Percent change from 1974
Coal	307	106	- 66	330	120	- 63
Oil	6,740	8,440	+ 25	6,390	8,680	+ 36
Gas	7,510	9,190	+ 22	7,930	6,790	- 14
Electricity	3,890	8,240	+ 117	3,570	6,810	+ 90
Total	18,447	25,976	+ 41*	18,220	22,400	+ 23†

*Fuel consumption would increase 22 percent.

†Fuel consumption would increase 6.5 percent.

The method used by the FEA in developing the data in Table 32 is briefly described below:

> "The Project Independence Evaluation System (PIES) is a model of the technologies, leadtimes, costs and geographical locations which affect energy commodities from the point of discovery, through production, transportation, conversion to more useful forms, and ultimately consumption by all sectors of the economy. Consumption (final demand) for a particular fuel depends on

> prices for that fuel, the prices of substitute fuels, the general level of economic activity, and the ability of consumers and capital stocks to adjust to these factors. For each year of analysis, FEA forecasts the demand for refined petroleum products, natural gas, electricity, and coal. These fuel demands are made for each Census region and for each end-use consuming sector — residential and commercial, industrial, and transportation. These demand forecasts are based on estimated prices and vary as prices change.
>
> "Energy supply is estimated separately for oil, natural gas, and coal. For each fuel, many different regions are separately evaluated to assess the differences between OCS and Alaskan oil or Appalachian and Western coal. For each region and fuel, reserve estimates are combined with the technologies and costs of finding and producing these fuels to estimate the cost of increasing supply. Major improvements have been made in the oil and gas models to estimate drilling patterns, link finding rates and enhanced recovery directly to revised reserve estimates, and account for changes in the depletion allowance. The coal supply estimates distinguish between various sulfur and Btu contents.
>
> "The PIES then attempts to match these energy demands as a function of fuel, sector, and price with the available supply in the regions which can supply these needs at the lowest price to find a balance or equilibrium. If supply is not available to satisfy the specific demands in an area, the prices are allowed to vary until supply and demand are brought into balance."

The FEA conducted the above analyses for three imported oil prices ($8, $13, and $16 per barrel) and four alternative energy strategies (business as usual, accelerated supply, accelerated conservation, and a combination of accelerated supply and conservation).

The FEA and BOM estimates differ in two important areas. First, with regard to gas, FEA predicts a 14 percent decrease in residential/commercial consumption while BOM predicts a 22 percent increase. For total U.S. consumption of natural gas, the FEA and BOM again differ but in the opposite direction from the residential sector; FEA predicts a 10 percent increase and BOM predicts a 10 percent decrease.

The second major difference is in electricity consumption where FEA predicts a 90 percent residential/commercial increase and BOM predicts a 117 percent increase. The BOM also predicts higher overall growth in electricity production of 112 percent compared to the FEA estimate of 77 percent. The BOM estimate is in line with the historical growth of 7 percent per year, but most experts believe that a lower growth rate near the 5 percent figure corresponding to the FEA estimate will prevail.

If the conflicts between the FEA and BOM estimates can be resolved, then the next problem is to determine how residential fuel use for space heating is related to the projections. The FEA projections include commercial fuel use and residential fuel for both space heating and air conditioning (heat pumps are used in the south and may increase in use).

An alternative approach is to consider changes in population and their probable impact on residential space heating requirements. One would expect that in a given area the increase in fuel for space heating would be directly proportional to population growth. Energy conservation measures and better uses in new houses could lead to a slower growth in residential space heating than the growth in population. Changes in population to 1985 are much easier to predict than changes in fuel use. The data in Table 33 show regional growth patterns and estimated 1985 fuel consumption based on these patterns. The predicted increase in fuel is less than the change in population because of the high growth rates in southern areas. An even smaller increase may occur because of energy conservation, improved heating efficiency and insulation, and a larger increase in electric heat. Residential fuel use in 1977 was down 2.5 percent from that used in 1976 according to recent BOM data. This decline was attributed largely to energy conservation measures although increased use of electricity (~ 1 percent) for residential heating also contributed.

TABLE 33. ESTIMATES OF RESIDENTIAL SPACE HEATING FUEL CONSUMPTION TO 1985 BASED ON POPULATION GROWTH

Region	1975 fuel consumption (10^{15} Joules)	Population change (percent)	1985 fuel consumption (10^{15} Joules)
New England	647	+ 4.2	674
Middle Atlantic	1,748	0.0	1,748
East North Central	1,727	+ 1.9	1,760
West North Central	741	+ 2.0	755
South Atlantic	589	+ 16.1	682
East South Central	212	+ 10.1	234
West South Central	388	+ 17.1	454
Mountain	287	+ 23.8	355
Pacific	494	+ 15.8	572
Total	6,833	+ 8.8	7,234*

*Fuel consumption would increase 6 percent from 1975 to 1985.

Our best estimate is that fuel usage for residential space heating will increase 4 percent from 1978 to 1985. Coal use decreased almost 50 percent over the 3-year period 1974 to 1976. However, an upswing in coal consumption for residential sources is anticipated through 1985, based on increased sales of coal-burning residential furnaces and space heaters.[23] A similar increase in wood consumption, over the estimated 1978 usage[24] of 105 × 10^{15} Joules, is anticipated. Considering all the data discussed in this section, we have projected a decrease in gas consumption of 2.9 percent by 1985. To achieve a total fuel usage increase of 4 percent, oil consumption will increase 3.5 percent. Projections for residential heating are summarized in Table 34. Fuel usage for 1978 was estimated from references in Appendix B.

TABLE 34. ESTIMATES OF RESIDENTIAL SPACE HEATING FUEL CONSUMPTION TO 1985 BASED ON FUEL TYPE

Fuel	Fuel consumption (10^{15} Joules)		Percent change
	1978	1985	
Coal	211	400	+ 90
Oil	2,532	2,620	+ 3.5
Gas	3,903	3,790	- 2.9
Wood	105	210	+ 100
Total	6,751	7,020	+ 4.0

5.2 CURRENT AND FUTURE NATIONWIDE EMISSIONS

Total 1978 national emissions from gas- and oil-fired residential combustion sources for space heating were determined based on combined test program and existing data emission factors and the estimated 1978 fuel consumption rates discussed previously. Nationwide emission totals for the criteria pollutants are presented in Table 35. Particulate, SO_x, and NO_x emissions from residential sources are relatively small, accounting for about 0.4, 1.2, and 2.5 percent, respectively, of emissions from all stationary combustion sources based on total estimates given in reference 4. Carbon monoxide emissions account for about 7 percent of emissions from stationary combustion sources, but less than 0.1 percent of total manmade carbon monoxide emissions. Motor vehicles are the major source of carbon monoxide emissions. Hydrocarbon emissions from the residential sources are roughly 10 percent of total emissions from stationary combustion sources. However, hydrocarbon emissions from the gas- and oil-fired residential combustion sources represent only about 0.1 percent of hydrocarbon emissions from all manmade sources of hydrocarbon emissions.

TABLE 35. RELATIONSHIP OF GAS- AND OIL-FIRED RESIDENTIAL HEATING SOURCE EMISSIONS TO TOTAL ESTIMATED EMISSIONS FROM COMBUSTION SOURCES

Pollutant	Emissions (tonnes/yr)		Percent of national emissions*	
	Gas-fired	Oil-fired	Gas-fired	Oil-fired
Particulates	8,200	20,100	0.1	0.3
SO_x	1,000	268,400	< 0.01	1.2
NO_x	128,800	139,300	1.2	1.3
CO	32,800	38,000	3.2	3.4
HC	12,800	23,300	3.7	6.5
Total POM	Neg	~ 500	Neg	< 0.01
Trace elements				
Pb	11	106	-	-
Cd	23	28	-	-
As	6	4	-	-
Ni	ND	734	-	-
Cr	< 1	73	-	-

*Based on reference 4 data. Trace element data are insufficient to calculate national emissions.

ND - Not Detected.

Current trace element emissions from oil-fired residential source heating systems are presented in Table 36. Emissions from gas-fired sources are considered to be negligible in comparison and are not reported in the table. Elements emitted in the largest amounts, with the exception of Ni, are relatively harmless; e.g., Ca, Al, and Mg. The trace element emissions listed in Table 36 represent about 22 percent of the total particulate emissions from oil-fired residential sources. The high percentage contribution of trace elements to total particulate is due in part to the assumption that all elements in the fuel are emitted with the flue gases.

TABLE 36. NATIONAL TRACE ELEMENT EMISSIONS FROM OIL-FIRED RESIDENTIAL SOURCES, 1978

Element	Emissions (tonnes/yr)
Pb	106
Ba	40
Sb	2
Cd	28
As	4
Zn	290
Cu	410
Ni	734
Fe	360
Cr	73
Ca	1150
Al	710
Mg	540

Emissions of POM from oil-fired residential sources are summarized in Table 37. POM emissions from the gas-fired residential sources were not detectable, with the exception of small quantities of naphthalene and its derivatives. The emission quantities have been calculated using the maximum values found in the test program.

TABLE 37. NATIONAL POM EMISSIONS FROM OIL-FIRED RESIDENTIAL SOURCES, 1978

Compound	Emissions (tonnes/yr)
Acenaphthene	31
Acetonaphthone	10
Anthracene	7
Azulene or naphthalene	68
Benzo(c)cinnoline	6
Biphenyl	67
Butyl phenanthrene	68
Dimethyl naphthalene	21
Dimethyl phenanthrene	1
Ethyl naphthalene	77
Fluorenone	29
Methyl anthracene	9
Methyl dibenzo thiophene	1
Methyl naphthalene	51
Methyl phenanthrene	1
Octyl phenanthrene	11
Phenanthrene	19
Phenanthrene quinone	19

6. REFERENCES

1. Hamersma, J. W., S. L. Reynolds, and R. F. Maddalone. IERL-RTP Procedures Manual: Level 1 Environmental Assessment. TRW Systems Group. Prepared for the U.S. Environmental Protection Agency. EPA-600/2-76-160a. NTIS No. PB 257 850. June 1976.

2. Barrett, R. E., S. E. Miller, and D. W. Locklin. Field Investigation of Emissions from Combustion Equipment for Space Heating. Battelle-Columbus Laboratories. Prepared for the U.S. Environmental Protection Agency. EPA-R2-73-084a. June 1973.

3. Compilation of Air Pollutant Emission Factors. Third edition, including Supplements 1-7. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Publication No. AP-42. NTIS No. PB 275 525. October 1977.

4. Surprenant, N., R. Hall, S. Slater, T. Susa, M. Sussman, and C. Young. Preliminary Emissions Assessment of Conventional Stationary Combustion Systems, Volume II - Final Report. GCA/Technology Division. Prepared for the U.S. Environmental Protection Agency. EPA-600/2-76-046b. NTIS No. PB 252 175. March 1976.

5. Statistical Abstract of the United States, 1976. U.S. Department of Commerce, Bureau of Census. 1976.

6. Current Housing Reports, Series H-150-74. Annual Housing Survey: 1974, Part A, General Housing Characteristics for the United States and Regions (advance report). U.S. Department of Commerce, Bureau of Census. 1976.

7. Offen, G. R., J. P. Kesselring, K. Lee, G. Poe, and K. J. Wolfe. Control of Particulate Matter from Oil Burners and Boilers. Aerotherm Division, Acurex Corporation. Prepared for the U.S. Environmental Protection Agency. EPA-450/3-76-005. NTIS No. PB 258 495. April 1976.

8. Brown, R. A., C. B. Moyer, and R. J. Schreiber. Feasibility of a Heat and Emission Loss Prevention System for Area Source Furnaces. Aerotherm Division, Acurex Corporation. Prepared for the U.S. Environmental Protection Agency. EPA-600/2-76-097. NTIS No. PB 253 945. April 1976.

9. Hall, R. E., T. H. Wasser, and E. E. Berkau. A Study of Air Pollutant Emissions from Residential Heating Systems. Control Systems Laboratory, Research Triangle Park, North Carolina. EPA-650/2-74-003. January 1974.

10. Eimutis, E. C. Mean Severities of Air Emissions From Combustion Sources. Monsanto Research Corporation. Interim report to the U.S. Environmental Protection Agency. December 1, 1976.

11. Levy, A., S. E. Miller, R. E. Barrett, E. J. Schulz, R. H. Melvin, W. H. Axtman, and D. W. Locklin. A Field Investigation of Emissions from Fuel Oil Combustion for Space Heating. Battelle-Columbus Laboratories. Prepared for the American Petroleum Institute. API Publication 4099. November 1971.

12. Barrett, R. E., D. W. Locklin, and S. E. Miller. Investigation of Particulate Emissions From Oil-Fired Residential Heating Units. Battelle-Columbus Laboratories. Prepared for the U.S. Environmental Protection Agency. EPA-650/2-74-026. March 1974.

13. Kalika, P. W., G. T. Brookman, and J. E. Yocom. Final Report to the American Gas Association for a Study on Measuring the Environmental Impact of Domestic Gas-Fired Heating Systems. The Research Company of New England. June 1974.

14. Kalika, P. W., G. T. Brookman, and J. E. Yocom. Second Quarterly Report to the American Gas Association for a Study on Measuring the Environmental Impact of Domestic Gas-Fired Heating Systems. The Research Company of New England. July 13, 1973.

15. Bartz, D. R. et al. Control of Oxides of Nitrogen from Stationary Sources in the South Coast Air Basin of California. KVB Engineering, Incorporated. Prepared for the California State Air Resources Board. ARB-R-2-1471-74-31. September 1974.

16. Katzman, L., and W. Weitzman. Study to Evaluate the Effects of Reducing the Firing Rates on Residential Oil Burner Installations. Walden Research Division of Abcor. Prepared for the U.S. Department of Commerce, National Bureau of Standards. Contract No. 6-35738.

17. Katzman, L., and R. D'Agostino. A Study to Evaluate the Effect of Performing Various Energy Saving Procedures on Residential Oil Burner Installations in the New England Area and to Gather Information on the Steady State and Dynamic Performance of These Installations. Walden Research Division of Abcor. Prepared for the U.S. Department of Commerce, National Bureau of Standards. Contract No. 5-35781.

18. Hangebrauck, R. P., D. J. von Lehmden, and J. E. Meeker. Sources of Polynuclear Hydrocarbons in the Atmosphere. Control Technology Research and Development Center for Air Pollution Control. Prepared for the U.S. Department of Health, Education and Welfare, Public Health Service. Environmental Health Series 999-AP-33. NTIS No. PB 260 073. 1967.

19. Cato, G. A., H. J. Buening, C. C. DeVivo, B. G. Morton, and J. M. Robinson. Field Testing: Application of Combustion Modification to Control Pollutant Emissions from Industrial Boilers, Phase I. KVB Engineering, Incorporated. Prepared for the U.S. Environmental Protection Agency. EPA-650/2-74-078a. NTIS No. PB 238 920. October 1974.

20. Homolya, J. B., and J. L. Cheney. An Assessment of Sulfuric Acid and Sulfate Emissions From the Combustion of Fossil Fuels. Workshop Proceeding on Primary Sulfate Emissions from Combustion Sources, Volume 2: Characterization. Prepared for the U.S. Environmental Protection Agency. EPA-600/9-78-020b. August 1978.

21. National Energy Outlook. Federal Energy Administration, Washington, D.C. NTIS No. PB 252 224. February 1976.

22. Dupree, W. G., and J. S. Corsentino. United States Energy Through the Year 2000 (Revised). U.S. Department of the Interior, Bureau of Mines. NTIS No. PB 250 600. December 1975.

23. DeAngelis, D. G., and R. B. Reznik. Source Assessment: Residential Combustion of Coal. Preliminary Report. Monsanto Research Corporation. Prepared for the U.S. Environmental Protection Agency. Contract No. 68-02-1874. 1978.

24. Personal Communication. W. Lyman Garrett, United States Forest Service, Burlington, Vermont.

APPENDIX A

CONVERSION FACTORS AND METRIC PREFIXES

CONVERSION FACTORS

To convert from	To	Multiply by
Degree Celsius (°C)	Degree Fahrenheit (°F)	1.8°C + 32
Gram (g)	Pound-mass	2.205×10^{-3}
Kilogram (kg)	Pound-mass	2.205
Metric ton (tonne)	Pound-mass	2.205×10^{3}
Gram/second (g/s)	Pound/hour (lb/hr)	7.94
Centimeter (cm)	Inch (in.)	0.394
Meter (m)	Inch (in.)	39.4
Meter (m)	Foot (ft)	3.281
Cubic meter (m^3)	Cubic foot (ft^3)	35.3
British thermal unit (Btu)	Joule (J)	1055
Joule (J)	British thermal unit (Btu)	9.48×10^{-4}

METRIC PREFIXES

Prefix	Symbol	Multiplication factor
Giga	G	10^{9}
Mega	M	10^{6}
Kilo	k	10^{3}
Centi	c	10^{-2}
Milli	m	10^{-3}
Micro	μ	10^{-6}
Nano	n	10^{-9}
Pico	p	10^{-12}

APPENDIX B

FUEL CONSUMPTION BY RESIDENTIAL SPACE HEATING SOURCES

FUEL CONSUMPTION BY RESIDENTIAL SPACE HEATING SOURCES

There is no generally accepted method for determining residential fuel use for space heating and similarly no agreement on the total amount of fuel used.

One approach is to determine the fuel required (Btu) for each dwelling unit (d.u.) for each heating degree-day (d.d.).* Climatological data are available from the U.S. Department of Commerce showing degree-days data annually as well as long-term averages for sites throughout the U.S.[1] Data are also available on the number of dwelling units in each state using each fuel.[2] These latter data are compiled by the Bureau of Census during deciannual surveys. Regional housing data are published annually.[3]

The amount of fuel required for each dwelling unit degree-day depends on housing characteristics, the amount of area heated, and the efficiency of the heating system. This factor can be determined through field surveys or engineering analyses. A heated area of 1600 ft^2 is generally accepted as typical. There is no debate about the steady state efficiency of residential heating systems (70 to 80 percent), but estimates of the overall efficiency that consider the effects of cycling and cold air infiltration range from 40 to 80 percent.[4] Available estimates for heating requirements (gas-fired systems) are 17,000 Btu/d.u.-d.d. from the U.S. Environmental Protection Agency,† 25,000 Btu/d.u.-d.d. from Walden Research, 26,000 Btu/d.u.-d.d. from Hittman Associates, and 32,000 to 34,000 Btu/d.u.-d.d. from the U.S. Federal Energy Administration.[6]

---

* A heating degree-day is a measure of the heating requirement. For a single day it is the difference between 65°F and the mean temperature. If the mean temperature is above 65°F, the heating degree-day total is zero.

† 17,000 Btu/d.u.-d.d. is equivalent to 32.2   10 Joules/d.u.-d.d. with degree-days given in degrees Celsius. EPA has also published a figure for oil of 25,000 Btu/d.u.-d.d. in Reference 5.

A second approach is to use fuel consumption data published annually in Mineral Industry Surveys by the U.S. Bureau of Mines.[7-11] However, the published residential gas consumption data include fuel used for space heating, cooling, water heating, and clothes drying. The problem is to separate space heating from other uses. On a national basis, 70 percent of residential gas consumption can be assumed to be used for space heating based on a study by Stanford Research Institute.[12] However, on a state-by-state basis this assumption is not valid; i.e., Florida probably uses a smaller percentage for heating. Data for other residential fuels are grouped with the commercial category, or grouped in other categories that make the determination of residential space heating fuel consumption difficult and uncertain.

A combination of the methods discussed above was used to develop the state-by-state residential space heating fuel consumption data presented in Table B-1. Regional data are presented in Table B-2. These data were developed from 1974 and 1975 fuel use data, 1970 and 1974 housing characteristics (the number of units that use each fuel in each state), and long-term average degree-day data. The most current estimate of the number of dwelling units in each state using each fuel for space heating was determined by updating the 1970 data to 1974 according to the regional growth rates in the period 1970 to 1974. These estimates can be considered as 1975 data but they would also apply to other years depending on the changes in the number of units and the heating requirements for that year.

National fuel use data for 1975 presented in Tables B-1 and B-2 have been updated using 1977 data from the Bureau of Mines Industry Surveys, trade journals,[13] and various government agency energy data reports.[14-19] National totals for 1976 and 1977 were obtained from these reports and extrapolated to 1978. The updated 1978 national fuel consumption totals are presented in Section 5 of this report. The methodology used for derivation of the fuel consumption data is discussed below.

U.S. consumption of natural gas for residential space heating was estimated to be 70 percent[12] of the total residential consumption. To determine the total U.S. dwelling unit-degree days, the number of housing units using gas heat was multiplied by the degree-days in each state, and these products

TABLE B-1. RESIDENTIAL SPACE HEATING FUEL USE BY STATE, 1975,[20] 10^{12} Btu/yr

State	Gas		Oil[‡]	Coal		Wood[**]
	Natural[*]	LPG[†]		Anthracite[§]	Bituminous[#]	
New England						
Maine	1	0.7	63.9	0.144	0.144	1.309
Vermont	1	1.2	24.0	0.231	0.020	0.383
New Hampshire	4	0.7	42.0	0.112	0.041	0.414
Massachusetts	71	2.5	216.1	0.682	0.015	0.204
Connecticut	24	1.6	109.9	0.179	0.007	0.131
Rhode Island	11	0.4	32.4	0.035	0.000	0.035
Middle Atlantic						
New York	314	8.9	548.7	6.893	0.000	0.936
New Jersey	102	1.9	167.6	2.150	0.000	0.124
Pennsylvania	230	3.8	231.1	37.803	0.000	0.899
East North Central						
Ohio	309	8.3	63.6	2.634	2.539	0.454
Indiana	115	11.3	57.3	1.971	0.766	0.553
Illinois	330	17.4	68.6	0.887	12.643	0.269
Michigan	285	10.1	98.7	3.138	0.671	0.657
Wisconsin	107	13.2	93.4	0.170	1.746	0.869
West North Central						
Minnesota	124	13.5	84.6	0.278	0.998	1.004
Iowa	83	15.5	39.8	0.000	0.771	0.165
Missouri	108	25.0	14.1	0.000	0.491	2.928
North Dakota	12	3.9	19.0	0.000	0.740	0.025
South Dakota	14	5.5	14.7	0.000	0.196	0.210
Nebraska	47	8.6	7.0	0.000	0.134	0.119
Kansas	65	9.2	1.3	0.000	0.067	0.259
South Atlantic						
Delaware	5	8.4	14.2	0.147	0.000	0.068
Maryland	57	1.8	66.8	1.351	0.338	0.552
District of Columbia	13	0.4	7.8	0.107	0.388	0.005
Virginia	36	1.8	67.2	0.224	0.359	3.160
West Virginia	37	1.0	5.7	1.474	3.729	0.383
North Carolina	16	5.0	76.4	0.000	2.235	3.506
South Carolina	11	3.7	21.0	0.000	0.851	2.065
Georgia	42	12.3	4.0	0.000	0.835	2.758
Florida	6	6.2	11.5	0.000	0.005	0.285

(continued)

TABLE B-1 (continued).

State	Gas		Oil[‡]	Coal		Wood[**]
	Natural[*]	LPG[†]		Anthracite[§]	Bituminous[#]	
East South Central						
Kentucky	51	7.3	9.7	0.000	8.436	1.925
Tennessee	30	4.6	6.6	0.000	6.171	3.429
Alabama	30	9.7	1.2	0.000	1.847	2.360
Mississippi	16	7.8	0.2	0.000	0.163	2.031
West South Central						
Arkansas	49	7.9	0.3	0.000	0.100	2.425
Louisiana	59	3.1	0.2	0.000	0.001	0.380
Oklahoma	52	9.1	0.2	0.000	0.022	0.813
Texas	164	18.3	0.7	0.000	0.011	0.944
Mountain						
Montana	28	3.3	5.3	0.000	0.321	0.461
Idaho	10	1.6	12.9	0.000	1.206	0.503
Wyoming	15	2.3	0.6	0.000	0.255	0.085
Colorado	86	7.5	1.8	0.000	0.838	0.150
New Mexico	22	2.9	0.9	0.000	0.039	0.920
Arizona	19	1.1	0.2	0.000	0.006	0.355
Utah	34	1.4	2.2	0.000	1.045	0.095
Nevada	6	1.3	2.3	0.000	0.026	0.073
Pacific						
Washington	35	2.5	62.2	0.000	0.665	1.568
Oregon	17	4.4	28.8	0.000	0.109	2.250
California	290	14.2	2.3	0.000	0.023	1.402
Alaska	6	0.2	10.3	0.000	0.290	0.423

[*] 1,022 Btu/ft^3.

[†] 90,000 Btu/gal.

[‡] 140,000 Btu/gal.

[§] 26×10^6 Btu/ton.

[#] 24×10^6 Btu/ton.

[**] 12×10^6 Btu/ton.

Note: To convert from 10^{12} Btu to 10^{15} Joules, multiply by 1.055.

TABLE B-2. U.S. RESIDENTIAL SPACE HEATING FUEL USE BY REGION, 1975, 10^{15} J/yr[*]

Region	Gas		Oil[§]	Coal		Wood[§§]	All fuels
	Natural[†]	LPG[‡]		Anthracite[#]	Bituminous[**]		
United States	3,794	316	2,550	64.3	54.9	49.9	6,833
Northeast	801	23	1,515	50.8	0.2	4.6	2,395
New England	119	7	515	1.5	0.2	2.6	647
Middle Atlantic	681	16	999	49.4	0.0	2.1	1,748
North Central	1,686	150	593	9.6	23.0	7.9	2,468
East North Central	1,208	85	403	9.3	19.4	3.0	1,727
West North Central	478	63	191	0.3	3.6	5.0	741
South	716	105	310	3.5	26.4	28.6	1,189
South Atlantic	237	35	290	3.5	9.2	13.5	589
East South Central	135	31	19	0.0	17.5	10.2	212
West South Central	342	40	1	0.0	0.1	4.9	388
West	597	38	133	0.0	5.1	8.8	781
Mountain	231	22	27	0.0	3.9	2.7	287
Pacific	366	15	105	0.0	1.2	5.9	494

[*] Totals may not agree because of rounding.

[†] 38×10^6 J/m^3 (1,022 Btu/ft^3).

[‡] 25.1×10^9 J/ℓ (90,000 Btu/gal).

[§] 39×10^9 J/ℓ (140,000 Btu/gal).

[#] 30×10^6 J/kg (26×10^6 Btu/ton).

[**] 27.9×10^6 J/kg (24×10^6 Btu/ton).

[§§] 13.9×10^6 J/kg (12×10^6 Btu/ton).

were summed, resulting in a U.S. total of 15.8×10^{10} dwelling unit-degree days. Comparing the estimated U.S. natural gas consumption of 3600×10^{12} Btu (3800×10^{15} J) in 1975 to the total dwelling unit-degree days indicates a heating requirement of 22,780 Btu/d.u.-d.d. which is consistent with estimates previously discussed. This heating requirement was multiplied by the number of dwelling units using gas heat and the average degree-days in each state to obtain state-by-state consumption.

Consumption of LPG in the U.S. is reported only as a residential/commercial total. The residential fraction was assumed to be the same as the residential fraction for natural gas. Also, 70 percent of the calculated residential consumption of LPG was assumed to be used for space heating, in line with published estimates for natural gas.[12] On this basis, U.S. residential space heating consumption of LPG was estimated to be 300×10^{12} Btu (316×10^{15} J). Calculation of the total U.S. LPG dwelling unit-degree days indicated a heating requirement of 19,600 Btu/d.u.-d.d. This heating requirement was used to determine LPG use for space heating by state from the number of dwelling units using LPG and the heating degree-days in each state.

Residential consumption of fuel oil for space heating was estimated from BOM and DOE energy data reports which provide annual fuel oil sales data for heating purposes. Approximately 76 percent of the fuel oil sold for heating is consumed by the residential sector.[16] This percentage was used to generate the 1975 residential fuel oil consumption total of 2400×10^{12} Btu (2550×10^{15} J). State-by-state-consumption was estimated using the methodology discussed above for natural gas.

Residential consumption of coal (anthracite and bituminous) on a state-by-state basis was determined from the number of dwelling units using coal, the average degree-days, and a reported consumption of 0.0012 ton/d.u.-d.d.[5] which is equivalent to about 30,000 Btu/d.u.-d.d. for an average house. Differences in housing characteristics on a state-by-state basis were also considered by multiplying the heating requirements by the ratio of the average rooms per house in the state to the national average of five rooms per house. In accordance with procedures outlined in reference 5, the calculated residential coal consumption was compared to anthracite deliveries in the selected state (reference 7). If the calculated consumption was less than the delivered anthracite, the difference was assumed to be bituminous. Total coal consumption for residential space heating in 1978 was estimated as 200×10^{12} Btu (211×10^{15} J). This figure is almost twice that reported for 1975 and is based primarily on sales data for solid burning residential furnaces and space heaters. Lignite consumption by residential sources is not significant,[20] ($\approx 2 \times 10^{12}$ Btu in 1978).

Minor quantities of wood are also used in rural areas for residential space heating. Wood consumption on a state-by-state basis was calculated from the number of dwelling units using wood for space heating,[2,3] the average heating degree-days, and the reported heating requirement of 0.0017 ton/d.u.-d.d. (20,000 Btu/d.u.-d.d.). Estimated total U.S. consumption was 100×10^{12} Btu (105×10^{15} J) in 1978, up from an estimated 47×10^{12} Btu (49.9×10^{15} J) in 1975.

REFERENCES

1. Local Climatological Data, Annual Summary With Comparative Data. U.S. Department of Commerce, Environmental Sciences Service Administration. Washington, D.C.

2. 1970 Census of Housing. Detailed Housing Characteristics. HC-B Series. U.S. Department of Commerce, Bureau of the Census. 1972

3. Current Housing Reports, Series H-150-75 and H-150-76, Annual Housing Survey: 1975 and 1976, Part A, General Housing Characteristics for the United States and Regions (advance report). U.S. Department of Commerce, Bureau of Census. 1976, 1977.

4. Brown, R. A., C. B. Moyer, and R. J. Schreiber. Feasibility of a Heat and Emission Loss Prevention System for Area Source Furnaces. Aerotherm Division, Acurex Corporation. Prepared for the U.S. Environmental Protection Agency. EPA-600/2-76-097. NTIS No. PB 253 945. April 1976.

5. Guide for Compiling a Comprehensive Emission Inventory, Second Edition. U.S. Environmental Protection Agency. APTD 1135. December 1974.

6. Benesh, F. Growth Effects of Major Land Use Projects: Volume II - Compilation of Land Use Based Emission Factors. Walden Research Division of Abcor. Prepared for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-450/3-76-012b. NTIS No. PB 255 302. September 1976.

7. Mineral Industry Surveys: Coal - Pennsylvania Anthracite in 1976. U.S. Department of the Interior, Bureau of Mines.

8. Mineral Industry Surveys: Bituminous Coal and Lignite Distribution, 1976. U.S. Department of the Interior, Bureau of Mines.

9. Mineral Industry Surveys: Natural Gas Production and Consumption, 1976. U.S. Department of the Interior, Bureau of Mines.

10. Mineral Industry Surveys: Liquefied Petroleum Gas Sales, Annual Summary for 1975, 1976, and 1977. U.S. Department of the Interior, Bureau of Mines.

11. Mineral Industry Surveys: Sales of Fuel Oil and Kerosene in 1975. U.S. Department of the Interior, Bureau of Mines.

12. Patterns of Energy Consumption in the United States. Stanford Research Institute, Office of Science and Technology. 1972.

13. Gas Facts. Annual Statistical Record for 1973 and 1977. Department of Statistics, American Gas Association.

14. Energy Data Reports: Fuel Oil Sales. Annual Summary for 1976 and 1977. U.S. Department of Energy, Energy Information Administration.

15. Energy Data Reports: Natural Gas Production and Consumption. Annual Summary for 1976 and 1977. U.S. Department of Energy, Energy Information Administration.

16. National Emission Data Systems: Fuel Use Report, 1974. U.S. Environmental Protection Agency. EPA-450/2-77-031. NTIS No. PB 284 658. April 1978.

17. Electric Power Statistics for 1974, 1975, and 1976. Federal Power Commission. Washington, D.C.

18. Quarterly Report: Third Quarter 1978. U.S. Department of Energy, Energy Information Administration. October 1978.

19. Energy Monthly Review: January 1979. U.S. Department of Energy, Energy Information Administration. DOE/EIA/0035/1(79).

20. Surprenant, N., R. Hall, S. Slater, T. Susa, M. Sussman, and C. Young. Preliminary Emissions Assessment of Conventional Stationary Combustion Systems, Volume II - Final Report. GCA/Technology Division. Prepared for the U.S. Environmental Protection Agency. EPA-600/2-76-046b. NTIS No. PB 252 175. March 1976.

APPENDIX C

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

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

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

The criteria for assessing the adequacy of emissions data were developed by considering both the reliability of the data and the variability of the data. The general approach was to utilize a three-step process as described below. This approach was applicable to the evaluation of the existing emissions data as well as emissions data collected during the course of this program. The following approach was used as appropriate in this assessment of gas- and oil-fired residential heating sources.

STEP 1

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

The first criterion applied was that only source test data would be accepted. A significant portion of the data base, and especially those

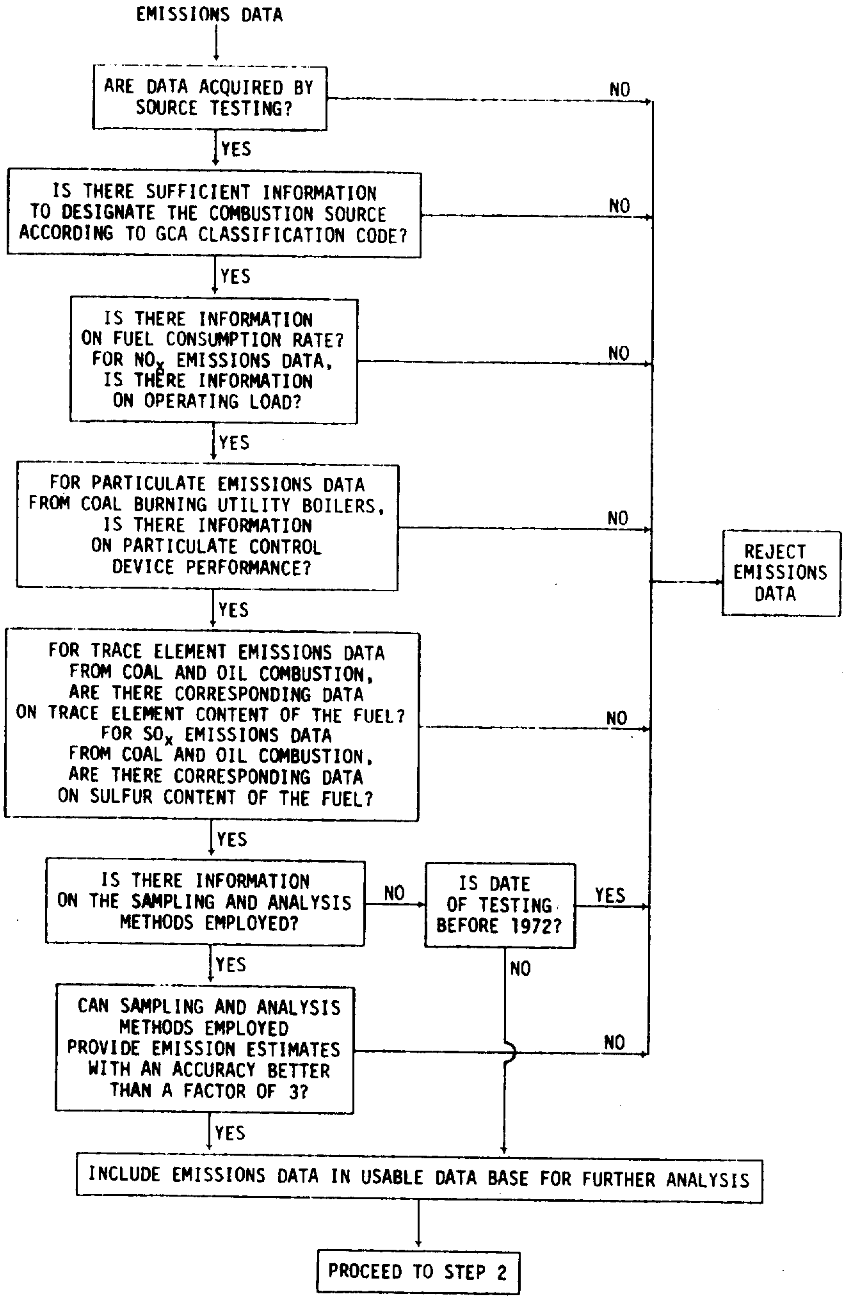


Figure C-1. Step 1 screening mechanism for emissions data.

contained in the National Emissions Data System (NEDS), was 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 have led to the obviously biased conclusion that the actual emissions were the same as those predicted by the standard emission factors.

The second criterion to be applied was an adequate description of the source. In order to further analyze the emissions data, sufficient information must be available to designate the combustion source according to the appropriate GCA classification code. As a minimum, the information provided should include the following: the function of the combustion source (electricity generation, industrial, commercial/institutional, or residential); the type of combustion (external or internal); 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 were judged to be valuable[†] and otherwise acceptable, efforts were 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 was 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 was, therefore, important to have an adequate definition of the test conditions that might affect emissions. As a minimum, information on the fuel consumption rate was required for the emissions data to be accepted. The fuel consumption rate was necessary for the calculation of emission factors. For NO_x emissions data, field and test results that did not include information on operating load were considered unacceptable because they could not 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 was considered as a useful parameter for data correlation but not an absolute requirement for data acceptance.

---

[*] Emission factors obtained in most instances from "Compilation of Air Pollutant Emission Factors," U.S. EPA Publication AP-42.

[†] In this context, emissions data for trace elements, POM, PCB, and organics were considered to be more valuable because of the paucity of data.

The fourth criterion for acceptance of emissions data for further analysis was an adequate definition of the pollution control device performance. Control device performance affects not only total emissions but also influences, 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. Since most coal burning utility boilers are equipped with particulate control devices, particulate emissions data from the coal burning utility sector were not considered acceptable unless accompanied by the particulate control device performance data. The application of particulate control devices is less common in the industrial, commercial/institutional, and residential sectors; it is also much less common in the oil burning utility sector and is nonexistent in the gas burning utility sector. For these combustion source types, emissions data were accepted as uncontrolled emissions data unless there was information implying the contrary. As noted in the foregoing discussions, acceptance of emissions data at this screening step did not suggest that the data were necessarily valid or reliable. In the second step of the data evaluation process, methods for rejecting outlying data points are defined. Controlled emissions data that have been mistakenly assumed to be uncontrolled emissions data due to lack of information were identified as outlying data points and were rejected in this second step.

The fifth criterion employed in judging the usefulness of the emissions data was the availability of fuel analysis data. This was 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 fuels; however, Ni, V, and Na are present in appreciable amounts in some fuel oil. In order 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 were not accompanied by analysis data on the trace element content of the fuel were not 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 did not also include information on the sulfur content of the fuel were therefore not accepted.

The last criterion that was applied was an evaluation of the accuracy of the sampling and analysis methods employed. In order to determine emissions from a given site to within a factor of three, both the sampling and analysis procedures employed must be capable of providing an accuracy which is better than a factor of three. The list of methods available for the sampling and analysis of general stream types and chemical classes and species is very extensive and is described in detail in two TRW reports.[1,2] In general, most of the sampling and analysis procedures recommended in these two references are adaptations of standard EPA, ASTM, and 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 were considered acceptable. Emissions data obtained by methods or techniques not listed in these two references were subjected to careful review and rejected if it was determined that the sampling or analysis method employed would not be able to provide emission estimates within an accuracy factor of three or better. Special emphasis was placed on the review of sampling and analysis methods used for obtaining PCB, POM, particulate sulfate, and trace element emissions data. In cases where information on the sampling and analysis methods employed was unavailable, the date of testing was used as the criterion for inclusion or rejection of the emissions data in the usable data base. Emissions data obtained before 1972 were generally considered as unacceptable due to the probable use of unreliable sampling or analysis procedures. The 1972 cut-off date was selected on the basis that EPA Method 5, 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 or used prior to 1972.

STEP 2

In the second step of the data evaluation process, emissions data which had been identified in the screening step as usable were subjected to further engineering and statistical analysis to determine the internal consistency of the test results and the variability in emission factors.

Emissions data included in the usable data base were first categorized according to the five-column GCA combustion system classification code and the unit operation from which the pollutants were emitted. For NO_x, the emissions data were further categorized according to the method of NO_x control: no control, staged firing, low excess air, reduced load, or flue gas recirculation. Emission factors for individual sites, normally expressed in the form of lb/MM Btu or lb/ton, were then claculated for each pollutant/unit operating pair. In the case of trace element stack emissions from coal and oil combustion, these emission factors were 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 were evaluated in terms of consistency of test results among sites. All the data points that were outside the upper and lower limits of reasonable data were subjected to detailed scrutiny and discarded unless there was additional information to reclassify the data into the correct category. The decision whether an outlier was a reasonable result or whether it could be discarded as being an improbable member of the group was 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 was then calculated. The variability is defined as

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

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 and is given in standard statistics texts. For the present program, the t values at 95 percent confidence level were 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 are 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 indicates 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 concentration 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:

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

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, are as follows:

Pollutant	Severity equation	
Particulate	$S = 70\ Qh^{-2}$	(3)
SO_x	$S = 50\ Qh^{-2}$	(4)
NO_x	$S = 315\ Qh^{-2.1}$	(5)
Hydrocarbons	$S = 162.5\ Qh^{-2}$	(6)
CO	$S = 0.78\ Qh^{-2}$	(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/yr
TNP = total number of plants (or 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:

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

where V_D = discharge flow rate, m^3/s
C_D = discharge concentration, g/m^3
S_G = leachable solid waste generation, g/s
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 was 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 is 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, there is no need for additional data.

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 $\bar{x}_u$:

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

   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,[3] an allowable uncertainty in emission factor of ± 70 percent (factor of three) would lead to an uncertainty of less than 10 in S_{calc}, which has been defined as the acceptable uncertainty factor for S.

The above decision criteria are based primarily on source severity factor considerations. A discrepancy arises, however, when comparing a source type having a few large plants with a source type having many small plants. In the latter case, each small plant may be emitting pollutants with $S < 0.05$, but the total impact on the environment may be significant because of the large number of plants involved. To overcome this problem, other criteria based on the air impact factors developed by MRC[4] (and defined in Attachment B) are added. These criteria have been applied to the residential source program:

1. If $S < 0.05$ for all pollutants emitted by the source type, but the environmental impact of these emissions is such that the ratio of the air impact factor for the source type to the largest air impact factor for conventional combustion sources exceeds 1 percent, determine those pollutant/unit operation pairs that contribute more than 10 percent to the value of the air impact factor for the source type.
2. If the variability in emission factor for any pollutant/unit operation pair determined is > 70 percent, the current data base is judged to be inadequate and there is need for additional data.

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

REFERENCES

1. Hamersma, J. W., S. L. Reynolds, and R. F. Maddalone. IERL-RTP Procedures Manual: Level 1 Environmental Assessment. TRW Systems Group. Prepared for the U.S. Environmental Protection Agency. EPA-600/2-76-160a. NTIS No. PB 257 850. June 1976.

2. Maddalone, R. F., and S. C. Quinlivan. Technical Manual for Inorganic Sampling and Analysis. TRW Document 29416-6038-RU-00. Review copy of report prepared by TRW Systems and Energy for the U.S. Environmental Protection Agency. April 1976.

3. Source Assessment: Analysis of Error. Draft copy of report prepared by Monsanto Research Corporation for the U.S. Environmental Protection Agency. November 1976.

4. Eimutis, E. C., C. M. Moscowitz, J. L. Delaney, R. P. Quill, and D. L. Zanders. Air, Water, and Solid Residue Prioritization Models for Conventional Combustion Sources. Prepared for the U.S. Environmental Protection Agency. EPA-600/2-76-176. p. 54. July 1976.

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 C-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, test the ratio of the difference between the first and third ranking observations to the difference between the first and next to last. For samples of 15 or more, use the ratio of the difference between the first and third ranking observations to the difference between the first and the second-from-last observation.

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

---

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

TABLE C-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

ATTACHMENT B

AIR IMPACT FACTOR

The mathematical model proposed by MRC to rank the impacts of the combustion sources is based on the impact factor defined below:

$$I_{Ax} = \sum_{j=1}^{K_x} P_j \left[\sum_{i=1}^{N} \left(\frac{\bar{X}_{ij}}{F_i} \right)^2 \frac{X^1_{ij}}{S_i} \right]^{1/2}$$

where I_{Ax} = impact factor, persons/km^2

K_x = number of sources emitting materials associated with source type x

P_j = population density in the region associated with the jth source, persons/km^2

N = number of materials emitted by each source

$\bar{X}_{ij}$ = calculated maximum ground level concentration of the ith material emitted by the jth source, g/m^3

F_i = environmental hazard potential factor of the ith material, g/m^3

X^1_{ij} = ambient concentration of the ith material in the region associated with the jth source, g/m^3

S_i = corresponding standard for the ith material (used only for criteria emissions, otherwise set X^1_{ij}/S_i equal to 1)

APPENDIX D

SUMMARY OF EXISTING EMISSIONS DATA

TABLE D-1. EMISSION RATES OF CO, HC, NO_x, SO_2, PARTICULATES, AND ALDEHYDES FROM GAS-FIRED RESIDENTIAL SOURCES

Test No.	Text reference	Furnace type*	Firing rate (10^6 J/hr)	Emissions (ng/J)						
				CO	Total HC	NO_x (as NO_2)	SO_2	Particulates		Aldehydes
								Filterable	Total	
1	13	1	100	38	54	0	-	0.67	-	3
2	13	1	100	24	27	59	-	0.74	-	8
3	13	1	100	50	70	17	-	0.27	55	4
4	13	1	100	17	8	48	-	0.02	-	0
5	13	1	100	15	7	33	-	0.23	-	19
6	13	1	100	11	-	110	-	0.13	-	12
7	13	1	100	19	2	16	-	0.08	-	10
8	13	1	100	40	19	35	-	1.66	-	4
9	13	4	162	26	55	129	-	0.46	-	7
10	13	2	84	65	49	82	-	0.21	-	9
11	13	2	84	57	38	0	-	0.23	-	4
12	13	2	84	10	10	16	-	0.08	-	1
13	13	2	84	28	25	104	-	0.13	-	7
14	13	2	84	40	84	45	-	0.78	-	3
15	13	2	84	21	12	4	-	0.08	-	1
16	13	2	84	14	17	72	-	0.21	-	1
17	13	2	84	20	14	0	-	0.13	-	7
18	13	3	118	18	38	66	-	0.19	-	2
19	13	3	118	18	37	32	-	0.23	-	1
20	13	2	84	44	46	34	-	0.08	-	5

(continued)

TABLE D-1 (continued).

Test No.	Text reference	Furnace type*	Firing rate (10^6 J/hr)	Emissions (ng/J)						
				CO	Total HC	NO_x (as NO_2)	SO_2	Particulates		Aldehydes
								Filterable	Total	
21	13	2	84	60	-	8	-	0.50	-	4
22	13	2	84	86	-	17	-	0.13	-	-
23	13	2	84	62	77	104	-	0.36	48	6
24	13	2	84	20	16	12	-	0.34	-	8
25	13	2	84	24	34	92	-	0.48	-	15
26	13	2	84	43	61	65	-	0.27	-	6
27	13	2	84	21	44	62	-	0.17	-	8
28	13	2	84	17	27	33	-	0.04	19	8
29†	13	2	84	75	-	90	-	0.61	-	8
30	13	2	84	70	71	40	-	0.69	-	0
31	13	2	84	22	8	96	-	1.47	-	0
32	13	2	84	37	79	119	-	0.36	-	0
33	13	2	84	25	18	59	-	1.37	11	0
34	13	2	84	34	20	13	-	0.27	-	10
35	13	2	84	15	28	34	-	0.23	-	12
36	13	2	84	24	10	65	-	0.29	-	3
37	13	2	84	13	28	41	-	0.08	-	1
38	13	2	84	29	19	70	-	0.19	-	7
39	13	1	100	31	-	74	-	0.84	14	0
40	13	1	100	19	18	108	-	0.38	-	10

(continued)

TABLE D-1 (continued).

Test No.	Text ref- er- ence	Furnace type*	Firing rate (10^6 J/hr)	Emissions (ng/J)						
				CO	Total HC	NO_x (as NO_2)	SO_2	Particulates		Aldehydes
								Filterable	Total	
41	13	6	84	43	27	41	-	0.27	-	8
42	13	7	113	46	38	84	-	0.93	-	17
43	13	2	84	17	30	39	-	0.17	-	13
44	13	2	84	40	-	10	-	0.55	-	8
45	13	5	79	55	80	21	-	0.34	9	17
46	13	2	84	103	64	53	-	1.05	-	8
47	13	7	113	23	26	46	-	0.13	-	11
48	13	5	79	53	52	63	-	0.32	-	15
49	13	2	84	17	35	57	-	0.29	-	11
50	13	2	84	63	-	34	-	0.21	-	1
51	14	8	140	6	10	15	-	0.86	-	87
52	14	8	140	10	13	89	-	0.27	-	184
53	14	8	140	9	2	40	-	0.02	-	4
54	14	8	140	27	37	66	-	0.00	-	18
55	14	8	140	19	10	75	-	0.08	-	5
56	14	8	140	29	103	43	-	0.02	-	5
57	14	10	140	11	11	40	-	0.04	-	5
58	14	8	140	14	26	0	-	0.02	-	3
59	14	10	140	10	8	0	-	0.00	-	5
60	14	10	140	16	30	71	-	0.00	-	4

(continued)

TABLE D-1 (continued).

Test No.	Text ref- er- ence	Furnace type*	Firing rate (10^6 J/hr)	Emissions (ng/J)						
				CO	Total HC	NO_x (as NO_2)	SO_2	Particulate		Aldehydes
								Filterable	Total	
61	14	8	140	15	31	18	-	0.02	-	1
62	14	8	140	20	24	22	-	0.02	-	12
63	14	8	140	5	17	25	-	0.02	-	1
64	14	8	140	12	5	40	-	0.17	-	1
65	14	8	140	14	102	315	-	0.11	-	0
66	14	8	140	13	4	50	-	0.13	-	5
67	14	8	140	31	4	48	-	0.17	-	4
68	14	8	140	15	22	44	-	0.02	-	3
69	14	8	140	13	14	0	-	0.00	-	4
70	14	8	140	451	435	20	-	0.15	-	3
71	14	8	140	38	38	37	-	0.02	-	5
72	14	8	140	15	13	32	-	0.06	-	6
73	14	8	140	11	25	79	-	0.02	-	5
74	14	10	140	8	12	40	-	0.06	-	2
75	14	9	38	10	23	48	-	0.25	-	5
76	14	8	140	20	19	118	-	0.34	-	3
77	14	8	140	15	36	90	-	0.02	-	3
78	14	8	140	13	36	126	-	0.02	-	5
79	14	8	140	15	136	230	-	0.32	-	5
80	14	10	140	21	42	39	-	0.25	-	6

(continued)

TABLE D-1 (continued).

Test No.	Text ref-er-ence	Furnace type*	Firing rate (10^6 J/hr)	Emissions (ng/J)						
				CO	Total HC	NO_x (as NO_2)	SO_2	Particulates		Aldehydes
								Filterable	Total	
81	14	8	140	52	13	149	-	0.13	-	4
82	14	8	140	11	30	83	-	0.11	-	5
83	14	8	140	12	141	0	-	0.97	-	15
84	14	8	140	11	12	63	-	0.76	-	11
85	14	8	140	40	36	26	-	1.77	-	16
86	14	8	140	18	15	59	-	0.04	-	34
87	14	8	140	26	42	39	-	0.06	-	28
88	14	8	140	31	48	144	-	0.21	-	5
89	14	8	140	241	29	10	-	0.46	-	4
90	14	8	140	22	147	39	-	0.48	-	60
91	14	8	140	28	51	63	-	0.00	-	54
92[‡]	14	8	140	8	42	98	-	0.11	-	153
93	14	8	140	11	6	22	0.00	0.11	-	5
94	14	8	140	11	11	81	0.04	0.38	-	21
95[‡]	14	8	140	14	30	63	-	0.61	-	53
96	14	8	140	733	315	57	1.00	0.40	-	11
97[§]	14	8	140	12	14	16	1.39	0.08	-	5
98	14	8	140	16	28	0	0.00	0.13	-	11
99	14	8	140	26	27	220	0.00	0.17	-	29
100	14	8	140	19	15	47	0.00	9.19	-	5

(continued)

TABLE D-1 (continued).

Test No.	Text ref-er-ence	Furnace type*	Firing rate (10^6 J/hr)	Emissions (ng/J)						
				CO	Total HC	NO_x (as NO_2)	SO_2	Particulates		Aldehydes
								Filterable	Total	
101	9	11	106	5	0	13	-	-	-	-
102	9	12	106	24	0	18	-	-	-	-
103	9	13	106	8	2	17	-	-	-	-
104	11	14	158	10	1	35	0.00	2.12	6.5	-
105	11	15	-	6	3	37	0.00	-	-	-
106	15	-	35	-	-	57	-	-	-	-
107	15	-	31	-	-	44	-	-	-	-
108	15	-	30	-	-	44	-	-	-	-
109	15	-	41	-	-	53	-	-	-	-
110	15	-	45	-	-	57	-	-	-	-
111	15	-	75	-	-	31	-	-	-	-
112	15	-	51	-	-	49	-	-	-	-
113	15	-	116	-	-	40	-	-	-	-
114	15	-	40	-	-	40	-	-	-	-
115	15	-	133	-	-	40	-	-	-	-
116	15	-	59	-	-	44	-	-	-	-
117	15	-	133	-	-	40	-	-	-	-
118	15	-	44	-	-	53	-	-	-	-
119	15	-	8	-	-	18	-	-	-	-
120	15	-	129	-	-	57	-	-	-	-

(continued)

TABLE D-1 (continued).

Test No.	Text reference	Furnace type*	Firing rate (10^6 J/hr)	Emissions (ng/J)						
				CO	Total HC	NO_x (as NO_2)	SO_2	Particulates		Aldehydes
								Filterable	Total	
121	15	–	44	–	–	40	–	–	–	–
122	15	–	32	–	–	31	–	–	–	–
123	15	–	49	–	–	31	–	–	–	–
124	15	–	135	–	–	44	–	–	–	–
125	15	–	114	–	–	44	–	–	–	–
126	15	–	89	–	–	57	–	–	–	–
127	15	–	44	–	–	49	–	–	–	–
128	15	–	160	–	–	35	–	–	–	–
129	15	–	38	–	–	66	–	–	–	–
130	15	–	38	–	–	35	–	–	–	–
131	15	–	145	–	–	35	–	–	–	–
132	15	–	119	–	–	40	–	–	–	–
133	15	–	45	–	–	49	–	–	–	–
134	15	–	39	–	–	31	–	–	–	–
135	15	–	89	–	–	31	–	–	–	–
136	15	–	228	–	–	80	–	–	–	–

(continued)

TABLE D-1 (continued).

---

[*] Furnace types:
1 - Thatcher (Comet) Forced Warm Air: 95,000 Btu input; 76,000 Btu output.
2 - Crane Sunnyland Forced Warm Air: 80,000 Btu input; 64,000 Btu output.
3 - Crane Sunnyday Hot Water Boiler: 112,000 Btu input; 89,600 Btu output.
4 - Crane Hot Water Boiler: 154,000 Btu input; 123,200 Btu output.
5 - Crane Hot Water Boiler: 75,000 Btu input; 60,000 Btu output.
6 - Crane Hot Water Boiler: 80,000 Btu input; 64,000 Btu output.
7 - Trimline Forced Warm Air: 107,000 Btu input; 85,000 Btu output.
8 - New Yorker Gas-Fired Boiler Model RG 133: 133,000 Btu input; 107,000 Btu output; 96,500 Btu net output.
9 - Rheem Hot Air System with 36,000 Btu/hr input hot water heater.
10 - Furnace 8 with a 36,000 Btu/hr output hot water heater.
11 - Williamson Furnace: 20 percent excess air.
12 - Bryant Boiler: 40 percent excess air.
13 - Bryant Furnace: 60 percent excess air.
14 - Forced Air Sectional Furnace: 137,000 Btu/hr firing rate.
15 - Forced Air Drum Furnace, Multiport Burner: 150,000 Btu/hr.

[†] Maladjusted furnace.

[‡] Questionable aldehyde sample.

[§] Questionable SO_2 sample.

TABLE D-2. EMISSION RATES OF CO, HC, NO_x, SO_2, AND PARTICULATES, AND BACHARACH SMOKE NUMBERS FROM OIL-FIRED RESIDENTIAL SOURCES

Test No.	Text ref- er- ence	Burner type*	Firing rate (10^6 J/hr)	Burner age	Sys- tem age	Effi- cien- cy	Stack gas			Per- cent excess air	Emissions (ng/J)					Bacharach smoke number
							Temper- ature (°C)	Per- cent CO_2	Per- cent O_2		CO	HC	NO_x	SO_2	Total partic- ulates	
1	2	FR	177	1	21	-	243	9.2	9.1	68	2	2	68	-	9	0.3
2	2	C	154	4	4	-	341	7.1	12.0	120	125	5	83	-	9	0.4
3	2	FR	199	1	1	-	254	8.4	9.0	75	5	2	47	-	11	1.0
4	2	S	263	2	9	-	271	7.1	11.1	109	3	2	64	-	18	0.5
5	2	FR	186	5	5	-	310	9.1	8.1	64	6	-	68	-	17	1.0
6	2	FR	133	2	8	-	282	6.6	11.9	126	94	5	86	-	25	1.3
7	2	C	111	18	18	-	188	9.4	7.1	55	11	1	62	-	35	9.0
8	2	C	162	18	18	-	299	7.5	10.3	95	7	3	74	-	17	0.2
9	2	C	202	20	20	-	277	7.9	10.5	94	21	1	64	-	17	0
10	2	C	145	5	5	-	285	7.0	11.4	114	186	5	76	-	26	0.2
11	2	FR	126	3	20	-	371	6.1	12.6	143	893	-	103	-	71	oily
12	2	C	89	11	11	-	227	9.4	7.4	55	9	1	46	-	19	2.7
13	11	C	162	12	12	-	288	7.2	10.0	98	0.5	1	64	114	18	3.0
14	11	C	109	13	13	-	288	6.7	10.8	112	8	2	69	73	14	3.0
15	11	C	443	9	9	-	360	9.0	9.5	73	4	1	51	62	17	1.0
16	11	C	180	30	30	-	354	7.0	10.6	105	8	0	57	126	13	7.0
17	11	C	160	15	15	-	246	4.5	14.5	216	231	146	44	-	96	-
18	11	FR	193	1	1	-	210	8.3	8.8	75	0	1	53	97	11	1.0
19	11	FR	310	12	12	-	210	10.0	6.9	49	0	1	46	123	7	3.0
20	11	FR	216	1	1	-	285	9.4	7.6	59	0.6	1	45	143	9	4.0
21	11	C	443	1	1	-	343	12.5	3.5	22	0	1	37	146	12	7.0
22	11	C	414	15	30	-	260	7.5	10.8	101	0	2	50	112	14	2.0
23	11	C	66	1	1	-	371	9.2	8.2	64	0	1	44	109	37	7.0
24	11	C	142	3	3	-	310	7.4	10.3	97	21	3	68	70	17	3.0
25	11	C	177	4	15	-	293	7.6	7.0	74	0	2	45	138	19	6.0
26	11	C	220	15	20	-	243	6.6	11.2	119	2	3	54	97	23	8.0
27	11	C	517	1	1	-	360	9.5	7.5	57	3	3	68	62	30	6.0
28	11	FR	236	1	8	-	271	6.7	11.3	118	4	3	61	65	13	2.0

(continued)

TABLE D-2 (continued).

Test No.	Text ref- er- ence	Burner type*	Firing rate (10^6 J/hr)	Burner age	Sys- tem age	Effi- cien- cy	Stack gas			Per- cent excess air	Emissions (ng/J)					Bacharach smoke number
							Temper- ature (°C)	Per- cent CO_2	Per- cent O_2		CO	HC	NO_x	SO_2	Total partic- ulates	
29	11	S	282	3	15	-	288	9.5	8.2	61	35	4	55	76	11	6.0
30	11	C	177	3	3	-	293	8.4	9.4	78	26	2	56	53	45	4.0
31	11	C	310	20	20	-	338	7.6	10.2	94	39	5	38	71	14	4.0
32	11	C	86	20	20	-	138	3.8	17.0	346	311	338	15	78	65	-
33	9	C	111	-	-	77	-	9.9	7.2	53	12	1	26	-	-	2.9
34	9	CI	111	-	-	71	-	8.2	9.5	80	14	1	30	-	-	1.3
35	9	CI	111	-	-	75	-	10.8	5.4	40	14	1	39	-	-	3
36	9	CI	111	-	-	72	-	9.1	8.5	66	14	1	29	-	-	2
37	9	CI	111	-	-	76	-	9.4	7.5	60	7	1	39	-	-	2
38	9	CI	111	-	-	83	-	12.6	3.7	20	12	1	29	-	-	1.2
39	9	FR	111	-	-	80	-	10.9	5.3	38	12	1	18	-	-	2
40	9	FR	111	-	-	81	-	11.6	4.6	31	12	1	33	-	-	2.5
41	9	FR	111	-	-	80	-	10.7	5.7	34	7	0	41	-	-	2.6
42	9	FR	111	-	-	73	-	9.3	7.9	63	14	1	27	-	-	1.1
43	9	FR	111	-	-	80	-	13.5	2.7	16	6	2	23	-	-	3.5
44	9	FR	111	-	-	70	-	7.9	9.3	86	23	2	34	-	-	2.2
45	9	FR	111	-	-	75	-	10.7	5.8	42	12	1	27	-	-	1.7
46	9	FR	111	-	-	83	-	12.2	3.7	18	5	0	27	-	-	1.4
47	9	FR	111	-	-	78	-	10.2	6.2	48	9	0	34	-	-	2.1
48	9	C	111	-	-	-	-	10.3	6.1	47	91	4	21	-	-	-
49	9	C	111	-	-	-	-	9.9	7.2	53	7	3	30	-	-	1.8
50	9	C	111	-	-	74	-	8.0	9.3	86	65	3	29	-	-	1.45
51	9	C	111	-	-	-	-	9.3	7.9	63	13	2	28	-	-	-
52	9	C	111	-	-	91	-	12.6	3.7	20	12	5	41	-	-	2.5
53	9	C	111	-	-	91	-	13.7	2.6	11	125	0	3	-	-	-
54	9	C	111	-	-	82	-	12.6	3.7	20	58	4	11	-	-	1.85
55	9	C	111	-	-	-	-	4.4	1.0	6	13	5	9	-	-	0.2
56	9	C	111	-	-	-	-	4.4	1.0	6	13	1	10	-	-	-

(continued)

TABLE D-2 (continued).

Test No.	Text ref- er- ence	Burner type*	Firing rate (10^6 J/hr)	Burner age	Sys- tem age	Effi- cien- cy	Stack gas			Per- cent excess air	Emissions (ng/J)					Bacharach smoke number
							Temper- ature (°C)	Per- cent CO_2	Per- cent O_2		CO	HC	NO_x	SO_2	Total partic- ulates	
57	9	C	111	-	-	84	-	1.8	3.7	25	47	6	28	-	-	-
58	9	C	111	-	-	-	-	8.9	8.5	68	10	-	11	-	-	-
59	12	FR	148	-	-	-	-	-	-	-	5	1	-	-	5	-
60	12	FR	148	-	-	-	-	-	-	-	12	1	-	-	4	-
61	12	FR	148	-	-	-	-	-	-	-	6	1	-	-	3	-
62	16	FR	244	15	40	56	477	7.0	-	-	-	-	-	-	-	7.0
63	16	C	199	25	48	47	396	4.5	-	-	-	-	-	-	-	7.0
64	16	FR	244	6	13	69	308	7.0	-	-	-	-	-	-	-	2.0
65	16	C	199	-	-	74	309	9.0	-	-	-	-	-	-	-	0
66	16	C	148	18	18	70	297	7.0	-	-	-	-	-	-	-	3.0
67	16	FR	177	3	20	75	177	5.0	-	-	-	-	-	-	-	0
68	16	FR	222	3	20	72	243	6.0	-	-	-	-	-	-	-	0
69	16	C	148	-	-	71	310	7.5	-	-	-	-	-	-	-	3
70	16	FR	185	4	4	72	352	12.0	-	-	-	-	-	-	-	1
71	16	C	199	15	20	71	271	6.5	-	-	-	-	-	-	-	4
72	16	C	222	10	-	72	329	8.5	-	-	-	-	-	-	-	1
73	16	FR	199	3	3	72	332	8.8	-	-	-	-	-	-	-	0
74	16	S	222	20	21	73	196	5.0	-	-	-	-	-	-	-	9
75	16	S	177	21	21	78	235	8.5	-	-	-	-	-	-	-	0
76	16	FR	148	3	3	73	339	10.5	-	-	-	-	-	-	-	3
77	16	FR	185	2	26	75	243	5.0	-	-	-	-	-	-	-	4
78	16	C	185	26	26	75	231	7.0	-	-	-	-	-	-	-	1
79	16	FR	258	5	25	75	371	11.5	-	-	-	-	-	-	-	1
80	16	C	222	-	-	73	366	10.0	-	-	-	-	-	-	-	1
81	16	C	185	20	45	71	361	9.0	-	-	-	-	-	-	-	9
82	16	C	199	-	-	76	235	7.5	-	-	-	-	-	-	-	0
83	16	C	148	26	26	65	320	6.0	-	-	-	-	-	-	-	0
84	16	C	177	20	-	64	310	5.5	-	-	-	-	-	-	-	1

(continued)

TABLE D-2 (continued).

Test No.	Text ref- er- ence	Burner type*	Firing rate (10^6 J/hr)	Burner age	Sys- tem age	Effi- cien- cy	Stack gas			Per- cent excess air	Emissions (ng/J)					Bacharach smoke number
							Temper- ature (°C)	Per- cent CO_2	Per- cent O_2		CO	HC	NO_x	SO_2	Total partic- ulates	
85	16	FR	177	3	20	75	293	9.0	-	-	-	-	-	-	-	0
86	16	S	222	15	15	72	432	11.5	-	-	-	-	-	-	-	9
87	16	C	185	35	35	58	271	4.0	-	-	-	-	-	-	-	1
88	16	C	148	25	-	76	263	8.5	-	-	-	-	-	-	-	6
89	16	C	185	20	35	82	177	8.5	-	-	-	-	-	-	-	2
90	16	C	295	30	30	77	316	11.0	-	-	-	-	-	-	-	1
91	16	C	185	20	20	67	318	6.5	-	-	-	-	-	-	-	5
92	16	C	148	30	35	67	268	5.5	-	-	-	-	-	-	-	6
93	16	FR	199	4	-	74	359	10.5	-	-	-	-	-	-	-	0
94	16	FR	185	4	-	81	291	13.0	-	-	-	-	-	-	-	5
95	16	C	185	-	-	71	275	6.5	-	-	-	-	-	-	-	8
96	16	C	332	5	40	61	359	6.0	-	-	-	-	-	-	-	0
97	16	C	126	40	40	69	338	7.5	-	-	-	-	-	-	-	0
98	16	C	665	-	-	73	299	8.0	-	-	-	-	-	-	-	0
99	16	FR	148	-	-	-	-	-	-	-	-	-	-	-	-	-
100	17	FR	199	-	-	79	233	9.5	-	-	-	-	-	-	-	0
101	17	C	148	-	-	-	-	-	-	-	-	-	-	-	-	-
102	17	C	126	-	-	-	-	-	-	-	-	-	-	-	-	-
103	17	C	148	-	-	-	-	-	-	-	-	-	-	-	-	-
104	17	FR	295	-	-	70	282	6.5	-	-	-	-	-	-	-	0
105	17	C	222	-	-	63	285	5.0	-	-	-	-	-	-	-	2
106	17	R	244	-	-	-	-	-	-	-	-	-	-	-	-	-
107	17	C	185	-	-	72	178	7.0	-	-	-	-	-	-	-	0
108	17	C	111	-	-	-	-	-	-	-	-	-	-	-	-	-
109	17	FR	244	-	-	74	383	11.0	-	-	-	-	-	-	-	0
110	17	C	332	-	-	80	143	6.0	-	-	-	-	-	-	-	3
111	17	S	443	-	-	79	256	10.0	-	-	-	-	-	-	-	2
112	17	S	177	-	-	78	260	9.5	-	-	-	-	-	-	-	5

(continued)

TABLE D-2 (continued).

Test No.	Text reference	Burner type*	Firing rate (10^6 J/hr)	Burner age	System age	Efficiency	Stack gas			Percent excess air	Emissions (ng/J)					Bacharach smoke number
							Temperature (°C)	Percent CO_2	Percent O_2		CO	HC	NO_x	SO_2	Total particulates	
113	17	FR	244	-	-	-	-	-	-	-	-	-	-	-	-	-
114	17	C	244	-	-	-	-	-	-	-	-	-	-	-	-	-
115	17	C	295	-	-	-	-	-	-	-	-	-	-	-	-	-
116	17	C	177	-	-	72	271	7.0	-	-	-	-	-	-	-	-
117	17	FR	148	-	-	74	346	11.0	-	-	-	-	-	-	-	0
118	17	FR	148	-	-	80	206	8.5	-	-	-	-	-	-	-	0
119	17	C	199	-	-	62	427	7.5	-	-	-	-	-	-	-	0
120	17	C	185	-	-	72	326	9.0	-	-	-	-	-	-	-	3
121	17	S	185	-	-	74	239	6.5	-	-	-	-	-	-	-	0
122	17	C	244	-	-	-	-	-	-	-	-	-	-	-	-	0
123	17	C	199	-	-	75	286	8.5	-	-	-	-	-	-	-	-
124	17	C	295	-	-	60	318	5.0	-	-	-	-	-	-	-	0
125	17	S	222	-	-	71	337	8.0	-	-	-	-	-	-	-	1
126	17	FR	148	-	-	73	352	9.5	-	-	-	-	-	-	-	0
127	17	C	148	-	-	76	256	8.0	-	-	-	-	-	-	-	0
128	17	S	222	-	-	79	234	9.0	-	-	-	-	-	-	-	0
129	17	FR	369	-	-	78	284	10.5	-	-	-	-	-	-	-	0
130	17	C	185	-	-	75	234	7.0	-	-	-	-	-	-	-	2
131	17	FR	244	-	-	73	296	8.0	-	-	-	-	-	-	-	1
132	17	C	199	-	-	67	403	8.5	-	-	-	-	-	-	-	0
133	17	C	199	-	-	78	243	8.5	-	-	-	-	-	-	-	2
134	17	S	199	-	-	77	287	10.0	-	-	-	-	-	-	-	1
135	17	FR	126	-	-	-	-	-	-	-	-	-	-	-	-	0
136	17	C	177	-	-	-	-	-	-	-	-	-	-	-	-	-
137	17	C	199	-	-	-	-	-	-	-	-	-	-	-	-	-

*Burner types:
FR - Flame Retention
C - Conventional
S - Shell
CI - Conventional with a combustion improving device
R - Rotary.

APPENDIX E

DATA REDUCTION PROCEDURE

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/m^3, $\mu g/m^3$). To convert these emissions data to the emission factor form, the following data reduction procedure[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 at stoichiometric conditions.

The average values of F for natural gas and various liquid fuels are given in Table E-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 kg/GJ can be computed using the following equation:

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

where s = subject emission species

M_s = molecular weight of species s.

For emission species measured on a mass concentration basis (mg/m^3 or µg/m^3) at 20°C, the emission factor expressed as kg/GJ can be computed using the following equation:

$$\begin{Bmatrix}\text{Emission}\\ \text{Factor}\end{Bmatrix} (\text{kg/GJ}) = \frac{\begin{Bmatrix}\text{Mass}\\ \text{Concentration}\end{Bmatrix}_s (\mu\text{g/m}^3) \times F \times 0.02404}{\begin{Bmatrix}\text{Fuel}\\ \text{Heating Value}\end{Bmatrix} (\text{kJ/kg fuel})} \qquad \frac{1}{1 - 4.762\ (O_2/100)}$$

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

TABLE E-1. FUEL COMPOSITION AND COMBUSTION CHARACTERISTICS*

Fuel	Elemental composition				F Factor	Higher heating value (kJ/kg)
	n_C	n_S	n_H	n_O		
Natural gas	0.06221	0	0.23116	0.00040	0.51215	53,310
No. 2 Distillate oil	0.06994	0.00006	0.13889	0.001125	0.45983	45,040
Kerosene	0.06994	0	0.15873	0	0.48234	47,710
Residual oil	0.7160	0.00031	0.10913	0.00125	0.44037	43,760

*The elemental composition and higher heating value data are obtained from Reference 2.

It should be noted that the data reduction procedure described here significantly minimizes errors introduced in data reduction by eliminating terms which 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 usually can be determined with great accuracy by gas chromatography.

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. The emission factor for NO_x (as NO_2) in kg/GJ is calculated as follows:

$$\left\{\begin{matrix}\text{Emission Factor} \\ \text{for } NO_x \text{ (as } NO_2\text{)}\end{matrix}\right\} = \frac{200 \times 0.51215 \times 46.0}{53310} \times \frac{1}{1 - 4.762 \times 0.15} = 0.309 \text{ kg/GJ.}$$

REFERENCES

1. Coppersmith, R. 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.

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

APPENDIX F

GAS- AND OIL-FIRED RESIDENTIAL SOURCE LABORATORY DATA

TABLE F-1. SSMS ANALYTICAL DATA: SITE 100

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
U	< 0.0001	< 0.030	< 0.0035	< 0.034	< 0.0010
TH	< 0.0001	< 0.044	< 0.0051	< 0.049	< 0.0015
BI	< 0.0001	< 0.014	< 0.0016	< 0.015	< 0.0005
PB	< 0.016	< 0.42	< 0.14	< 0.58	< 0.018
TL	< 0.0001	< 0.017	< 0.0020	< 0.019	< 0.0006
AU	< 0.0001	< 0.023	< 0.0026	< 0.025	< 0.0008
IR	< 0.0001	< 0.035	< 0.0040	< 0.039	< 0.0012
OS	< 0.0001	< 0.038	< 0.0044	< 0.043	< 0.0013
RE	< 0.0001	< 0.024	< 0.0028	< 0.027	< 0.0008
W	< 0.0003	< 0.32	< 0.0037	< 0.33	< 0.0100
HF	< 0.0001	< 0.040	< 0.0046	< 0.045	< 0.0014
LU	< 0.0001	< 0.0094	< 0.0011	< 0.011	< 0.0003
YB	< 0.0001	< 0.014	< 0.0016	< 0.015	< 0.0005
TM	< 0.0001	< 0.0084	< 0.0010	< 0.0094	< 0.0003
ER	< 0.0001	< 0.025	< 0.0028	< 0.028	< 0.0008
HO	< 0.0007	< 0.0081	< 0.0009	< 0.0097	< 0.0003
DY	< 0.0001	< 0.014	< 0.0016	< 0.016	< 0.0005
TB	< 0.0001	< 0.0038	< 0.0004	< 0.0043	< 0.0001
GD	< 0.0001	< 0.014	< 0.0016	< 0.016	< 0.0005
EU	< 0.0001	< 0.0064	< 0.0007	< 0.0071	< 0.0002
SM	< 0.0001	< 0.024	< 0.0028	< 0.027	< 0.0008
ND	0.0004	< 0.031	< 0.0035	0.0004 TO 0.034	< 0.0001 TO 0.0010
PR	< 0.0001	< 0.0054	< 0.0006	< 0.0060	< 0.0002
CE	< 0.0001	< 0.031	< 0.0008	< 0.0001 TO 0.032	< 0.0001 TO 0.0010
LA	< 0.0001	0.0059	< 0.0009	0.0059	0.0002
BA	0.0056	< 0.34	0.045	0.050 TO 0.34	0.0015 TO 0.0100
CS	< 0.0001	< 0.0013	< 0.0003	< 0.0016	< 0.0001
I	< 0.0001	0.022	< 0.0024	0.022	0.0007
TE	< 0.0001	< 0.018	< 0.0020	< 0.020	< 0.0006
SB	0.0010	0.039	< 0.0029	0.040	0.0012
SN	0.0015	< 1.0	< 0.19	0.0015 TO 1.2	< 0.0001 TO 0.037
CD	< 0.0013	< 0.15	< 0.018	< 0.17	< 0.0052
PD	< 0.0001	< 0.018	< 0.0020	< 0.020	< 0.0006
RH	< 0.0001	< 0.0061	< 0.0007	< 0.0069	< 0.0002

TABLE F-1 (continued).

SFe 100

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
RU	< 0.0001	< 0.023	< 0.0026	< 0.025	< 0.0008
MO	0.0002	< 0.090	< 0.051	0.0002 TO 0.14	< 0.0001 TO 0.0043
NB	< 0.0001	0.0028	< 0.0003	0.0028	< 0.0001
ZR	0.0009	0.074	0.0040	0.079	0.0024
Y	< 0.0001	0.087	< 0.0047	0.087	0.0027
SR	< 0.0004	< 0.16	< 0.0088	< 0.17	< 0.0051
RB	0.0003	< 0.0086	< 0.0044	0.0003 TO 0.013	< 0.0001 TO 0.0004
BR	0.0025	< 0.098	< 0.035	0.0025 TO 0.13	< 0.0001 TO 0.0041
SE	0.0007	< 0.079	< 0.0014	0.0007 TO 0.080	< 0.0001 TO 0.0025
AS	0.0004	< 0.047	< 0.0054	0.0004 TO 0.053	< 0.0001 TO 0.0016
GE	< 0.0001	< 0.0084	< 0.0010	< 0.0094	< 0.0003
GA	< 0.0001	< 0.0034	< 0.0004	< 0.0001 TO 0.0038	< 0.0001 TO 0.0001
ZN	< 0.32	< 1.2	< 0.67	< 2.2	< 0.068
CU	< 0.15	< 26.	< 0.069	< 26.	< 0.79
NI	< 0.41	< 3.7	< 0.36	< 4.5	< 0.14
CO	< 0.0019	< 0.035	< 0.0061	0.0019 TO 0.042	< 0.0001 TO 0.0013
FE	< 0.077	< 5.8	< 0.67	< 6.5	< 0.20
MN	0.0031	0.076	< 0.052	0.079	0.0024
CR	0.0014	< 1.5	< 0.35	0.0014 TO 1.8	< 0.0001 TO 0.055
V	0.0002	< 0.022	< 0.0035	0.0002 TO 0.025	< 0.0001 TO 0.0008
TI	0.0075	< 0.053	< 0.041	0.0075 TO 0.093	0.0002 TO 0.0029
CA	0.069	< 5.3	< 0.62	0.069 TO 6.0	0.0021 TO 0.18
K	< 0.12	< 1.9	< 0.35	< 2.3	< 0.072
CL	0.20	< 7.7	< 6.2	0.20 TO 14.	0.0060 TO 0.43
S	< 0.37	< 9.3	< 16.	< 26.	< 0.79
P	0.014	< 1.9	< 0.16	0.014 TO 2.1	0.0004 TO 0.064
SI	< 1.3	230.	< 12.	230.	7.1
AL	MC	< 1.8	< 0.47	-	-
MG	< 0.098	< 1.2	< 0.13	< 1.4	< 0.043
NA	MC	< 11.	< 0.39	-	-
F	0.0059	< 0.052	< 0.027	0.0059 TO 0.078	0.0002 TO 0.0024
B	0.032	0.99	< 0.0049	1.0	0.031
BE	< 0.0001	< 0.0017	< 0.0004	< 0.0001 TO 0.0022	< 0.0001 TO 0.0001

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.

TABLE F-2. SSMS ANALYTICAL DATA: SITE 101

ELEMENT	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
U	< 0.014	< 0.0018	< 0.015	< 0.0005
TH	< 0.020	< 0.0026	< 0.022	< 0.0007
BI	< 0.0061	< 0.0008	< 0.0069	< 0.0002
PB	< 0.40	< 0.35	< 0.75	< 0.025
TL	< 0.0076	< 0.0010	< 0.0087	< 0.0003
AU	< 0.0100	< 0.0014	< 0.012	< 0.0004
IR	< 0.016	< 0.0021	< 0.018	< 0.0006
OS	< 0.017	< 0.0023	< 0.019	< 0.0006
RE	< 0.011	< 0.0014	< 0.012	< 0.0004
W	< 0.49	0.0067	0.0067 TO 0.49	0.0002 TO 0.017
HF	< 0.018	< 0.0024	< 0.020	< 0.0007
LU	< 0.0042	< 0.0006	< 0.0048	< 0.0002
YB	< 0.0061	< 0.0008	< 0.0070	< 0.0002
TM	< 0.0038	< 0.0005	< 0.0043	< 0.0001
ER	< 0.011	< 0.0015	< 0.013	< 0.0004
HO	< 0.0036	< 0.0005	< 0.0041	< 0.0001
DY	< 0.0063	< 0.0008	< 0.0072	< 0.0002
TB	< 0.0017	< 0.0004	< 0.0022	< 0.0001
GD	< 0.0063	< 0.0008	< 0.0071	< 0.0002
EU	< 0.0028	< 0.0004	< 0.0033	< 0.0001
SM	< 0.011	< 0.0015	< 0.012	< 0.0004
ND	< 0.014	< 0.0018	< 0.016	< 0.0005
PR	< 0.0024	< 0.0004	< 0.0029	< 0.0001
CE	< 0.023	< 0.0004	< 0.023	< 0.0008
LA	< 0.0035	< 0.0005	< 0.0040	< 0.0001
BA	< 0.34	< 0.045	< 0.39	< 0.013
CS	0.0020	< 0.0004	0.0020	< 0.0001
I	< 0.0094	< 0.0013	< 0.011	< 0.0004
TE	< 0.0079	< 0.0011	< 0.0090	< 0.0003
SB	0.019	< 0.073	0.019 TO 0.073	0.0006 TO 0.0025
SN	1.4	< 0.44	1.4	0.047
CD	< 0.0096	0.44	0.44	0.015
PD	< 0.0079	< 0.0010	< 0.0089	< 0.0003
RH	< 0.0027	< 0.0004	< 0.0032	< 0.0001

Site 101

TABLE F-2 (continued).

ELEMENT	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
RU	< 0.0100	< 0.0013	< 0.011	< 0.0004
MO	< 0.20	0.053	0.053 TO 0.20	0.0018 TO 0.0066
NB	< 0.0012	0.0008	0.0008	< 0.0001
ZR	0.0046	0.0062	0.011	0.0004
Y	< 0.0018	< 0.0004	< 0.0023	< 0.0001
SR	< 0.071	< 0.030	< 0.100	< 0.0034
RB	< 0.012	< 0.0051	< 0.017	< 0.0006
BR	< 0.042	< 0.059	< 0.100	< 0.0034
SE	< 0.023	< 0.0007	< 0.024	< 0.0008
AS	< 0.015	0.086	0.086	0.0029
GE	< 0.0038	< 0.0005	< 0.0043	< 0.0001
GA	< 0.0015	< 0.0004	< 0.0020	< 0.0001
ZN	< 0.37	< 11.	< 11.	< 0.37
CU	< 16.	< 3.5	< 20.	< 0.66
NI	< 0.69	< 6.7	< 7.4	< 0.25
CO	< 0.0053	0.49	0.49	0.017
FE	< 1.9	< 15.	< 17.	< 0.56
MN	< 0.045	0.45	0.45	0.015
CR	< 0.28	< 2.4	< 2.7	< 0.091
V	< 0.0045	< 0.013	< 0.017	< 0.0006
CA	< 5.3	< 4.4	< 9.7	< 0.33
K	< 0.84	7.2	7.2	0.24
CL	< 3.5	3.9	3.9	0.13
S	< 6.2	**	**	110.
P	< 1.3	< 0.80	< 2.1	< 0.071
SI	< 6.7	< 28.	< 35.	< 1.2
AL	< 1.8	< 5.2	< 7.0	< 0.24
MG	< 0.80	< 1.1	< 1.9	< 0.062
NA	< 5.1	< 2.0	< 7.1	< 0.24
F	< 0.069	46.	46.	1.6
B	0.063	< 0.17	0.063 TO 0.17	0.0021 TO 0.0057
BE	< 0.0005	< 0.0002	< 0.0008	< 0.0001
LI	< 0.0026	< 0.0035	< 0.0060	< 0.0002

** INDICATES A VALUE EXCEEDING ONE GRAM.

TABLE F-3. SSMS ANALYTICAL DATA: SITE 102

ELEMENT	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
U	< 0.014	< 0.0074	< 0.021	< 0.0006
TH	< 0.020	< 0.011	< 0.030	< 0.0009
BI	< 0.0061	< 0.0033	< 0.0094	< 0.0003
PB	< 0.54	< 0.14	< 0.69	< 0.021
TL	< 0.0076	< 0.0041	< 0.012	< 0.0004
AU	< 0.0100	< 0.0055	< 0.016	< 0.0005
IR	< 0.016	< 0.0085	< 0.024	< 0.0007
OS	< 0.017	< 0.0092	< 0.026	< 0.0008
RE	< 0.011	< 0.0058	< 0.017	< 0.0005
W	< 0.014	< 0.0078	< 0.022	< 0.0007
HF	< 0.018	< 0.0097	< 0.028	< 0.0008
LU	< 0.0042	< 0.0023	< 0.0065	< 0.0002
YB	< 0.0061	< 0.0033	< 0.0095	< 0.0003
TM	< 0.0038	< 0.0020	< 0.0058	< 0.0002
ER	< 0.011	< 0.0060	< 0.017	< 0.0005
HO	< 0.0036	< 0.0020	< 0.0056	< 0.0002
DY	< 0.0063	< 0.0034	< 0.0097	< 0.0003
TB	< 0.0017	< 0.0009	< 0.0026	< 0.0001
GD	< 0.0063	< 0.0034	< 0.0097	< 0.0003
EU	< 0.0028	< 0.0015	< 0.0044	< 0.0001
SM	< 0.011	< 0.0059	< 0.017	< 0.0005
ND	0.055	< 0.0074	0.055	0.0017
PR	0.018	< 0.0013	0.018	0.0006
CE	0.15	< 0.0018	0.15	0.0047
LA	0.076	< 0.0019	0.076	0.0023
BA	0.26	0.040	0.30	0.0091
CS	< 0.0007	0.0001	0.0001 TO 0.0007	< 0.0001 TO 0.0001
I	< 0.0094	< 0.0051	< 0.014	< 0.0004
TE	< 0.0079	< 0.0043	< 0.012	< 0.0004
SB	< 0.016	0.029	0.029	0.0009
SN	< 0.16	< 0.12	< 0.28	< 0.0085
CD	0.100	< 0.12	0.100	0.0031
PD	< 0.0079	< 0.0043	< 0.012	< 0.0004
RH	< 0.0027	< 0.0015	< 0.0042	< 0.0001

Site 102

TABLE F-3 (continued).

ELEMENT	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
RU	< 0.0100	< 0.0055	< 0.016	< 0.0005
MO	0.23	0.057	0.28	0.0087
NB	0.025	0.0010	0.026	0.0008
ZR	0.0033	< 0.0024	0.0033	< 0.0001
Y	< 0.0018	< 0.0010	< 0.0028	< 0.0001
SR	< 0.23	0.0074	0.0074 TO 0.23	0.0002 TO 0.0070
RB	< 0.0039	< 0.0013	< 0.0051	< 0.0002
BR	< 0.029	< 0.0073	< 0.037	< 0.0011
SE	< 0.0054	< 0.0091	< 0.014	< 0.0004
AS	< 0.15	0.033	0.033 TO 0.15	0.0010 TO 0.0045
GE	< 0.0038	< 0.0020	< 0.0058	< 0.0002
GA	< 0.0015	< 0.0008	< 0.0024	< 0.0001
ZN	< 1.6	< 0.86	< 2.5	< 0.075
CU	69.	< 0.62	69.	2.1
NI	< 6.9	< 0.76	< 7.6	< 0.23
CO	< 0.076	0.0084	0.0084 TO 0.076	0.0003 TO 0.0023
FE	< 8.1	< 4.4	< 13.	< 0.38
MN	< 0.20	0.16	0.16	0.0048
CR	1.3	< 0.98	1.3	0.039
V	< 0.020	< 0.0073	< 0.028	< 0.0008
TI	< 0.032	< 0.085	< 0.12	< 0.0036
CA	< 11.	< 2.9	< 14.	< 0.44
K	< 4.1	< 2.2	< 6.3	< 0.19
CL	< 24.	19.	19.	0.59
S	< 32.	< 7.8	< 40.	< 1.2
P	< 1.3	< 0.98	< 2.3	< 0.070
SI	< 2.1	< 7.6	< 9.7	< 0.30
AL	1.3	< 0.43	1.3	0.040
MG	< 1.6	< 0.43	< 2.1	< 0.064
NA	< 5.1	< 8.2	< 13.	< 0.41
F	< 0.069	< 0.037	< 0.11	< 0.0033
B	0.13	< 0.0100	0.13	0.0041
BE	< 0.0007	< 0.0018	< 0.0026	< 0.0001
LI	< 0.0026	< 0.0001	< 0.0026	< 0.0001

TABLE F-4. SSMS ANALYTICAL DATA: SITE 103

ELEMENT	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
U	< 0.022	< 0.0033	< 0.026	< 0.0008
TH	< 0.032	< 0.0048	< 0.037	< 0.0011
BI	< 0.0100	< 0.0015	< 0.011	< 0.0003
PB	< 0.65	< 0.097	< 0.75	< 0.023
TL	< 0.012	< 0.0019	< 0.014	< 0.0004
AU	< 0.017	< 0.0025	< 0.019	< 0.0006
IR	< 0.026	< 0.0038	< 0.029	< 0.0009
OS	< 0.028	< 0.0042	< 0.032	< 0.0010
RE	< 0.018	< 0.0026	< 0.020	< 0.0006
W	< 0.024	0.013	0.013	0.0004
HF	< 0.029	< 0.0044	< 0.034	< 0.0010
LU	< 0.0069	< 0.0010	< 0.0079	< 0.0002
YB	< 0.0100	< 0.0015	< 0.012	< 0.0003
TM	< 0.0061	< 0.0009	< 0.0071	< 0.0002
ER	< 0.018	< 0.0027	< 0.021	< 0.0006
HO	< 0.0059	< 0.0009	< 0.0068	< 0.0002
DY	< 0.0100	< 0.0015	< 0.012	< 0.0004
TB	< 0.0028	< 0.0004	< 0.0032	< 0.0001
GD	< 0.0100	< 0.0015	< 0.012	< 0.0004
EU	< 0.0046	< 0.0007	< 0.0053	< 0.0002
SM	< 0.018	< 0.0027	< 0.021	< 0.0006
ND	< 0.022	< 0.0033	< 0.026	< 0.0008
PR	< 0.0040	< 0.0006	< 0.0045	< 0.0001
CE	< 0.0080	0.0017	0.0017 TO 0.0080	< 0.0001 TO 0.0002
LA	< 0.0058	< 0.0009	< 0.0066	< 0.0002
BA	< 0.25	< 0.037	< 0.29	< 0.0087
CS	0.0007	0.0007	0.0014	< 0.0001
I	< 0.015	< 0.0023	< 0.018	< 0.0005
TE	< 0.013	< 0.0019	< 0.015	< 0.0004
SB	< 0.025	< 0.0038	< 0.029	< 0.0009
SN	< 0.54	< 0.18	< 0.72	< 0.022
CD	< 0.036	< 0.080	< 0.12	< 0.0035
PD	< 0.013	< 0.0019	< 0.015	< 0.0004
RH	< 0.0045	< 0.0007	< 0.0052	< 0.0002

Site 103

TABLE F-4 (continued).

ELEMENT	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
RU	< 0.017	< 0.0025	< 0.019	< 0.0006
MO	< 0.048	0.019	0.019 TO 0.048	0.0006 TO 0.0015
NB	< 0.0019	0.0003	0.0003 TO 0.0019	< 0.0001 TO 0.0001
ZR	0.0036	< 0.0011	0.0036	0.0001
Y	< 0.0030	< 0.0004	< 0.0034	< 0.0001
SR	< 0.078	0.015	0.015 TO 0.078	0.0005 TO 0.0024
RB	< 0.0090	< 0.0028	< 0.012	< 0.0004
BR	< 0.098	< 0.024	< 0.12	< 0.0037
SE	< 0.0088	< 0.0013	< 0.0100	< 0.0003
AS	< 0.015	< 0.016	< 0.031	< 0.0009
GE	< 0.0062	< 0.0009	< 0.0071	< 0.0002
GA	< 0.0025	< 0.0004	< 0.0029	< 0.0001
ZN	< 0.91	< 0.91	< 1.8	< 0.055
CU	< 2.7	< 0.13	< 2.8	< 0.086
NI	< 5.3	< 0.80	< 6.1	< 0.19
CO	< 0.019	< 0.013	< 0.031	< 0.0009
FE	< 2.1	< 2.7	< 4.8	< 0.15
MN	< 0.22	0.088	0.088 TO 0.22	0.0027 TO 0.0067
CR	< 0.66	< 1.1	< 1.8	< 0.054
V	0.012	< 0.0049	0.012	0.0004
TI	< 0.086	< 0.013	< 0.099	< 0.0030
CA	< 8.0	< 1.9	< 9.9	< 0.30
K	< 3.2	< 1.0	< 4.2	< 0.13
CL	< 40.	2.8	2.8 TO 40.	0.086 TO 1.2
S	< 68.	< 11.	< 79.	< 2.4
P	< 3.0	< 0.15	< 3.1	< 0.094
SI	< 12.	< 2.5	< 14.	< 0.44
AL	< 1.3	< 0.32	< 1.6	< 0.049
MG	< 1.3	< 0.62	< 1.9	< 0.058
NA	< 5.1	< 3.7	< 8.8	< 0.27
F	< 0.11	< 0.017	< 0.13	< 0.0040
B	0.032	< 0.0065	0.032	0.0010
BE	< 0.0040	< 0.0001	< 0.0041	< 0.0001
LI	< 0.013	< 0.0013	< 0.015	< 0.0004

TABLE F-5. SSMS ANALYTICAL DATA: SITE 104

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
U	< 0.0001	< 0.014	< 0.0073	< 0.021	< 0.0006
TH	< 0.0001	< 0.020	< 0.011	< 0.030	< 0.0009
BI	< 0.0002	< 0.0061	< 0.0033	< 0.0096	< 0.0003
PB	< 0.0071	< 0.27	0.075	0.075 TO 0.27	0.0023 TO 0.0085
TL	< 0.0001	< 0.0076	< 0.0041	< 0.012	< 0.0004
AU	< 0.0001	< 0.0100	< 0.0055	< 0.016	< 0.0005
IR	< 0.0001	< 0.016	< 0.0084	< 0.024	< 0.0007
OS	< 0.0001	< 0.017	< 0.0091	< 0.026	< 0.0008
RE	< 0.0001	< 0.011	< 0.0058	< 0.017	< 0.0005
W	< 0.0001	< 0.014	< 0.36	< 0.37	< 0.012
HF	< 0.0001	< 0.018	< 0.0097	< 0.028	< 0.0009
LU	< 0.0001	< 0.0042	< 0.0023	< 0.0065	< 0.0002
YB	< 0.0001	< 0.0061	< 0.0033	< 0.0094	< 0.0003
TM	< 0.0001	< 0.0038	< 0.0020	< 0.0058	< 0.0002
ER	< 0.0001	< 0.011	< 0.0059	< 0.017	< 0.0005
HO	< 0.0001	< 0.0036	< 0.0019	< 0.0056	< 0.0002
DY	< 0.0001	< 0.0063	< 0.0034	< 0.0097	< 0.0003
TB	< 0.0001	< 0.0017	< 0.0009	< 0.0026	< 0.0001
GD	< 0.0001	< 0.0063	< 0.0034	< 0.0096	< 0.0003
EU	< 0.0001	< 0.0028	< 0.0015	< 0.0044	< 0.0001
SM	< 0.0001	< 0.011	< 0.0059	< 0.017	< 0.0005
ND	< 0.0001	< 0.014	< 0.0073	< 0.021	< 0.0006
PR	< 0.0001	< 0.0024	< 0.0013	< 0.0037	< 0.0001
CE	< 0.0001	< 0.0033	0.0061	0.0061	0.0002
LA	< 0.0001	< 0.0035	< 0.0019	< 0.0055	< 0.0002
BA	< 0.0041	< 0.34	0.080	0.080 TO 0.34	0.0025 TO 0.011
CS	< 0.0001	< 0.0007	0.0015	0.0015	< 0.0001
I	< 0.0001	< 0.0094	< 0.0050	< 0.015	< 0.0004
TE	< 0.0001	< 0.0079	< 0.0042	< 0.012	< 0.0004
SB	< 0.0002	< 0.032	< 0.021	< 0.053	< 0.0016
SN	< 0.0009	< 0.45	< 12.	< 12.	< 0.38
CD	< 0.0009	< 0.031	< 0.17	< 0.21	< 0.0064
PD	< 0.0001	< 0.0079	< 0.0042	< 0.012	< 0.0004
RH	< 0.0001	< 0.0027	< 0.0015	< 0.0042	< 0.0001

Site 105

TABLE F-5 (continued).

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
RU	< 0.0001	< 0.0100	< 0.0054	< 0.016	< 0.0005
MO	< 0.0001	< 0.020	0.036	0.036	0.0011
NB	< 0.0001	< 0.0012	< 0.0006	< 0.0018	< 0.0001
ZR	0.0008	< 0.0044	< 0.0024	0.0008 TO 0.0068	< 0.0001 TO 0.0002
Y	< 0.0001	< 0.0018	< 0.0097	< 0.0001 TO 0.012	< 0.0001 TO 0.0004
SR	< 0.0006	< 0.071	0.0051	0.0051 TO 0.072	0.0002 TO 0.0022
RB	< 0.0001	< 0.0024	< 0.0021	< 0.0045	< 0.0001
BR	< 0.0008	< 0.029	< 0.016	< 0.046	< 0.0014
SE	< 0.0009	< 0.0054	< 0.0029	< 0.0092	< 0.0003
AS	< 0.0002	< 0.015	< 0.017	< 0.032	< 0.0010
GE	< 0.0001	< 0.0038	< 0.0020	< 0.0058	< 0.0002
GA	< 0.0001	< 0.0015	< 0.0008	< 0.0024	< 0.0001
ZN	0.80	< 0.39	< 0.63	0.80	0.025
CU	< 0.19	< 1.6	< 0.30	< 2.1	< 0.066
NI	< 0.41	< 0.49	< 0.82	< 1.7	< 0.053
CU	< 0.0001	< 0.0053	< 0.013	< 0.018	< 0.0006
FE	< 0.022	< 1.3	< 6.9	< 8.2	< 0.26
MN	< 0.0012	< 0.064	< 0.72	< 0.79	< 0.024
CR	0.0008	< 0.14	< 0.65	0.0008 TO 0.79	< 0.0001 TO 0.024
V	< 0.0001	< 0.0065	< 0.0073	< 0.014	< 0.0004
TI	< 0.0042	< 0.016	< 0.0004	< 0.020	< 0.0006
CA	0.037	< 3.4	< 1.3	0.037 TO 4.7	0.0012 TO 0.15
K	< 0.078	< 1.4	< 1.1	< 2.5	< 0.078
CL	< 0.029	< 7.3	5.1	5.1	0.16
S	< 0.53	< 14.	< 37.	< 51.	< 1.6
P	< 0.0099	< 1.8	< 9.7	< 12.	< 0.36
SI	< 1.3	< 3.3	< 7.6	< 12.	< 0.38
AL	MC	< 1.3	< 0.31	-	-
MG	< 0.068	< 0.74	< 0.40	< 1.2	< 0.037
NA	MC	< 5.1	< 8.2	-	-
F	< 0.0038	< 0.100	0.015	0.015 TO 0.11	0.0005 TO 0.0033
B	0.047	0.013	< 0.0068	0.060	0.0019
BE	< 0.0001	< 0.0002	< 0.0003	< 0.0005	< 0.0001
LI	< 0.0001	< 0.011	< 0.0014	< 0.0001 TO 0.013	< 0.0001 TO 0.0004

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.

TABLE F-6. SSMS ANALYTICAL DATA: SITE 300

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0001	< 0.0036	0.015	0.015	0.0002	< 0.062	< 0.0010
TH	< 0.0002	< 0.0052	< 0.0062	< 0.012	< 0.0001	< 0.090	< 0.0015
BI	0.0004	< 0.011	< 0.0019	0.0004 TO 0.013	< 0.0001 TO 0.0001	< 0.059	< 0.0010
PB	1.5	< 0.0034	0.077	1.6	0.017	2.0	0.033
TL	< 0.0001	< 0.0020	< 0.0024	< 0.0045	< 0.0001	< 0.035	< 0.0006
AU	< 0.0001	< 0.0027	< 0.0032	< 0.0060	< 0.0001	< 0.046	< 0.0008
IR	< 0.0001	< 0.0042	< 0.0050	< 0.0093	< 0.0001	< 0.072	< 0.0012
OS	< 0.0002	< 0.0045	< 0.0054	< 0.0100	< 0.0001	< 0.078	< 0.0013
RE	< 0.0001	< 0.0029	< 0.0034	< 0.0064	< 0.0001	< 0.049	< 0.0008
W	0.0002	< 0.0038	0.023	0.023	0.0002	< 0.066	< 0.0011
HF	< 0.0002	< 0.0048	< 0.0057	< 0.011	< 0.0001	< 0.082	< 0.0013
LU	< 0.0001	< 0.0011	< 0.0013	< 0.0025	< 0.0001	< 0.019	< 0.0003
YB	< 0.0001	< 0.0016	< 0.0019	< 0.0036	< 0.0001	< 0.028	< 0.0005
TM	< 0.0001	< 0.0010	< 0.0012	< 0.0022	< 0.0001	< 0.017	< 0.0003
ER	< 0.0001	< 0.0029	< 0.0035	< 0.0065	< 0.0001	< 0.050	< 0.0008
HO	< 0.0001	< 0.0010	< 0.0011	< 0.0021	< 0.0001	< 0.017	< 0.0003
DY	< 0.0001	< 0.0017	< 0.0020	< 0.0037	< 0.0001	< 0.029	< 0.0005
TB	< 0.0001	< 0.0004	< 0.0005	< 0.0010	< 0.0001	< 0.0078	< 0.0001
GD	< 0.0001	< 0.0017	< 0.0020	< 0.0037	< 0.0001	< 0.029	< 0.0005
EU	< 0.0001	< 0.0007	< 0.0009	< 0.0017	< 0.0001	< 0.013	< 0.0002
SM	< 0.0001	< 0.0029	< 0.0035	< 0.0065	< 0.0001	< 0.050	< 0.0008
ND	< 0.0001	< 0.0036	< 0.0043	< 0.0081	< 0.0001	0.11	0.0018
PR	< 0.0001	< 0.0006	< 0.0008	< 0.0014	< 0.0001	0.024	0.0004
CE	< 0.0001	< 0.0061	0.0016	0.0016 TO 0.0061	< 0.0001 TO 0.0001	0.23	0.0038
LA	< 0.0005	< 0.0020	0.0039	0.0039	< 0.0001	0.17	0.0028
BA	< 0.048	0.078	0.76	0.83	0.0091	1.1	0.018
CS	< 0.0001	0.016	< 0.0013	0.016	0.0002	< 0.0026	< 0.0001
I	< 0.0001	< 0.0025	< 0.0030	< 0.0056	< 0.0001	< 0.043	< 0.0007
TE	< 0.0001	< 0.0021	< 0.0025	< 0.0047	< 0.0001	< 0.036	< 0.0006
SB	< 0.0015	0.0070	0.0071	0.014	0.0001	0.036	0.0006
SN	< 0.022	0.041	< 0.070	0.041 TO 0.092	0.0004 TO 0.0010	0.24	0.0039
CD	0.067	< 0.0026	0.012	0.079	0.0009	0.22	0.0037
PD	< 0.0001	< 0.0021	< 0.0025	< 0.0047	< 0.0001	< 0.036	< 0.0006
RH	< 0.0001	< 0.0007	< 0.0009	< 0.0016	< 0.0001	< 0.013	< 0.0002

Site 300

TABLE F-6 (continued).

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0001	< 0.0027	< 0.0032	< 0.0060	< 0.0001	< 0.046	< 0.0008
MO	0.0037	0.0098	0.0100	0.024	0.0003	0.22	0.0037
NB	< 0.0001	0.0009	0.0039	0.0048	< 0.0001	0.056	0.0009
ZR	0.036	< 0.0082	0.028	0.064	0.0007	0.15	0.0025
Y	0.0001	0.0004	< 0.0006	0.0005	< 0.0001	0.0087	0.0001
SR	< 0.0047	0.017	0.0059	0.023	0.0002	0.36	0.0059
RB	0.0006	0.023	0.0018	0.025	0.0003	0.026	0.0004
BR	< 0.0029	< 0.026	0.030	0.030	0.0003	0.100	0.0016
SE	< 0.0072	0.014	< 0.023	0.014 TO 0.030	0.0002 TO 0.0003	< 0.025	< 0.0004
AS	< 0.0044	0.018	0.0048	0.022	0.0002	0.048	0.0008
GE	< 0.0001	< 0.0010	< 0.0012	< 0.0022	< 0.0001	< 0.017	< 0.0003
GA	< 0.0001	0.0020	< 0.021	0.0020 TO 0.021	< 0.0001 TO 0.0002	< 0.0070	< 0.0001
ZN	< 0.55	< 0.31	1.0	1.0	0.011	4.8	0.079
CU	0.17	< 0.31	< 0.51	0.17 TO 0.81	0.0019 TO 0.0088	6.7	0.11
NI	0.66	< 0.60	< 1.0	0.66 TO 1.6	0.0071 TO 0.018	23.	0.37
CD	< 0.0052	0.0029	0.0066	0.0095	< 0.0001	0.17	0.0028
FE	< 0.53	0.40	2.3	2.7	0.029	9.4	0.15
MN	< 0.044	0.100	0.064	0.17	0.0018	6.2	0.100
CR	< 0.020	0.068	< 0.057	0.068	0.0007	2.8	0.046
V	< 0.0013	0.0089	0.0031	0.012	0.0001	0.12	0.0019
TI	0.041	0.025	0.12	0.18	0.0020	0.54	0.0088
CA	< 0.75	< 1.4	2.3	2.3	0.025	21.	0.34
K	< 0.60	< 0.22	1.3	1.3	0.014	5.1	0.084
CL	< 0.15	0.096	0.31	0.40	0.0044	< 11.	< 0.18
S	12.	< 2.6	1.5	13.	0.14	320.	5.2
P	< 0.085	< 0.16	0.16	0.16	0.0017	< 3.9	< 0.065
SI	< 7.2	2.0	9.5	11.	0.12	< 96.	< 1.6
AL	< 0.38	0.43	2.0	2.4	0.026	10.	0.17
MG	< 0.23	< 1.0	1.2	1.2	0.013	8.7	0.14
NA	< 0.50	< 1.3	7.7	7.7	0.083	< 33.	< 0.54
F	< 0.0032	0.14	1.1	1.2	0.015	< 0.11	< 0.0017
B	< 0.026	0.064	1.4	1.4	0.016	< 0.040	< 0.0007
BE	< 0.0001	< 0.0006	0.0086	0.0066	< 0.0001	< 0.0011	< 0.0001
LI	< 0.0004	0.0030	0.029	0.031	0.0003	0.038	0.0006

TABLE F-7. SSMS ANALYTICAL DATA: SITE 301

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0017	< 0.0046	< 0.021	< 0.027	< 0.0003	< 0.016	< 0.0002
TH	< 0.0025	< 0.0067	< 0.030	< 0.039	< 0.0004	< 0.023	< 0.0003
BI	< 0.0008	< 0.0021	< 0.0093	< 0.012	< 0.0001	< 0.015	< 0.0002
PB	< 1.1	< 0.30	< 0.41	< 1.8	< 0.021	1.5	0.024
TL	< 0.0010	< 0.0026	< 0.012	< 0.015	< 0.0002	< 0.0089	< 0.0001
AU	< 0.0013	< 0.0034	< 0.016	< 0.020	< 0.0002	< 0.012	< 0.0002
IR	< 0.0020	< 0.0053	< 0.024	< 0.031	< 0.0003	< 0.018	< 0.0003
OS	< 0.0022	< 0.0058	< 0.026	< 0.034	< 0.0004	< 0.020	< 0.0003
RE	< 0.0014	< 0.0036	< 0.016	< 0.021	< 0.0002	< 0.013	< 0.0002
W	< 0.0018	< 0.0049	< 0.24	< 0.25	< 0.0028	< 0.13	< 0.0020
HF	< 0.0023	< 0.0061	< 0.027	< 0.036	< 0.0004	< 0.021	< 0.0003
LU	< 0.0005	< 0.0014	< 0.0064	< 0.0084	< 0.0001	< 0.0049	< 0.0001
YB	< 0.0008	< 0.0021	< 0.0093	< 0.012	< 0.0001	< 0.0071	< 0.0001
TM	< 0.0005	< 0.0013	< 0.0057	< 0.0075	< 0.0001	< 0.0044	< 0.0001
ER	< 0.0014	< 0.0037	< 0.017	< 0.022	< 0.0002	< 0.013	< 0.0002
HO	< 0.0005	< 0.0012	< 0.0055	< 0.0072	< 0.0001	< 0.0042	< 0.0001
DY	< 0.0008	< 0.0021	< 0.0096	< 0.013	< 0.0001	< 0.0073	< 0.0001
TB	< 0.0002	< 0.0006	< 0.0026	< 0.0034	< 0.0001	< 0.0020	< 0.0001
GD	< 0.0008	< 0.0021	< 0.0095	< 0.012	< 0.0001	< 0.0073	< 0.0001
EU	< 0.0004	< 0.0010	< 0.0043	< 0.0056	< 0.0001	< 0.0033	< 0.0001
SM	< 0.0014	< 0.0037	< 0.017	< 0.022	< 0.0002	< 0.013	< 0.0002
ND	< 0.0017	0.0078	< 0.021	0.0078 TO 0.023	< 0.0001 TO 0.0003	0.029	0.0004
PR	< 0.0003	0.0029	< 0.0037	0.0029	< 0.0001	0.0098	0.0001
CE	0.0034	< 0.023	0.017	0.021	0.0002	0.19	0.0029
LA	< 0.0009	< 0.0051	< 0.0054	< 0.011	< 0.0001	0.064	0.0010
BA	< 0.43	< 0.11	0.053	0.053 TO 0.54	0.0006 TO 0.0062	0.42	0.0066
CS	< 0.0003	< 0.0002	< 0.0009	< 0.0014	< 0.0001	< 0.0020	< 0.0001
I	< 0.0012	< 0.0032	< 0.014	< 0.019	< 0.0002	< 0.011	< 0.0002
TE	< 0.0010	< 0.0027	< 0.012	< 0.016	< 0.0002	< 0.0092	< 0.0001
SB	< 0.0049	< 0.0056	0.12	0.12	0.0013	0.018	0.0003
SN	< 0.0010	0.020	< 3.2	0.020 TO 3.2	0.0002 TO 0.036	0.32	0.0049
CD	0.0098	0.028	< 0.015	0.038	0.0004	0.24	0.0038
PD	< 0.0010	< 0.0027	< 0.012	< 0.016	< 0.0002	< 0.0091	< 0.0001
RH	< 0.0003	< 0.0009	< 0.0042	< 0.0055	< 0.0001	< 0.0032	< 0.0001

Site 301

TABLE F-7 (continued).

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0013	< 0.0034	< 0.015	< 0.020	< 0.0002	< 0.012	< 0.0002
MO	< 0.0051	0.0095	0.31	0.32	0.0036	0.082	0.0013
NB	< 0.0001	0.0014	0.0038	0.0052	< 0.0001	0.0100	0.0002
ZR	< 0.012	< 0.022	0.0094	0.0094 TO 0.034	0.0001 TO 0.0004	0.026	0.0004
Y	< 0.0002	< 0.0006	< 0.0028	< 0.0036	< 0.0001	0.0033	< 0.0001
SR	0.0025	0.015	0.12	0.13	0.0015	0.13	0.0020
RB	0.0011	0.0016	< 0.59	0.0021 TO 0.59	< 0.0001 TO 0.0067	0.0100	0.0002
BR	< 0.0076	< 0.046	< 0.021	< 0.074	< 0.0008	0.055	0.0008
SE	0.0071	< 0.0018	< 0.017	0.0071 TO 0.019	< 0.0001 TO 0.0002	< 0.0062	< 0.0001
AS	0.0075	< 0.011	0.029	0.036	0.0004	0.012	0.0002
GE	< 0.0005	< 0.0013	< 0.0056	< 0.0075	< 0.0001	< 0.0044	< 0.0001
GA	< 0.0021	< 0.0005	< 0.0023	< 0.0050	< 0.0001	< 0.0020	< 0.0001
ZN	1.3	0.94	< 0.057	2.2	0.025	2.2	0.035
CU	0.38	< 0.89	< 2.5	0.38 TO 3.4	0.0043 TO 0.039	5.7	0.088
NI	0.91	< 1.1	< 2.5	0.91 TO 3.6	0.0100 TO 0.041	13.	0.20
CO	< 0.0020	0.0051	0.028	0.033	0.0004	0.19	0.0029
FE	< 2.3	< 1.8	2.8	2.8	0.032	3.8	0.058
MN	< 0.057	< 0.068	0.19	0.19	0.0022	0.29	0.0045
CR	< 0.026	< 0.15	1.0	1.0	0.011	0.51	0.0079
V	< 0.0026	< 0.033	0.0100	0.0100 TO 0.035	0.0001 TO 0.0004	< 0.052	< 0.0008
TI	0.068	< 0.038	0.12	0.19	0.0021	0.19	0.0029
CA	< 1.4	1.4	5.3	6.8	0.077	< 8.9	< 0.14
K	< 1.1	< 1.4	3.1	3.1	0.035	4.1	0.064
CL	0.31	0.41	< 0.37	0.72	0.0082	< 2.8	< 0.044
S	20.	54.	9.0	83.	0.94	300.	4.6
P	< 0.23	< 0.61	4.3	4.3	0.049	< 1.0	< 0.016
SI	< 8.5	< 3.4	11.	11.	0.13	< 12.	< 0.18
AL	0.62	< 2.0	0.20	0.82 TO 2.0	0.0093 TO 0.022	5.1	0.079
MG	< 0.62	< 1.8	0.32	0.32 TO 2.4	0.0036 TO 0.028	1.5	0.023
NA	MC	< 5.1	4.7	*	*	< 18.	< 0.27
F	< 0.063	0.0039	< 0.075	0.0039 TO 0.14	< 0.0001 TO 0.0016	< 0.027	< 0.0004

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.

TABLE F-8. SSMS ANALYTICAL DATA: SITE 302

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0009	< 0.0095	< 0.0100	< 0.0001	< 0.025	< 0.0001
TH	< 0.0013	< 0.014	< 0.015	< 0.0001	< 0.036	< 0.0002
BI	< 0.0004	< 0.0043	< 0.0047	< 0.0001	< 0.011	< 0.0001
PB	< 0.36	0.31	0.31	0.0030	< 0.49	< 0.0029
TL	< 0.0005	< 0.0053	< 0.0058	< 0.0001	< 0.014	< 0.0001
AU	< 0.0007	< 0.0071	< 0.0077	< 0.0001	< 0.019	< 0.0001
IR	< 0.0010	< 0.011	< 0.012	< 0.0001	< 0.029	< 0.0002
OS	< 0.0011	< 0.012	< 0.013	< 0.0001	< 0.031	< 0.0002
RE	< 0.0007	< 0.0075	< 0.0082	< 0.0001	< 0.020	< 0.0001
W	< 0.0009	< 0.0100	< 0.011	< 0.0001	< 0.027	< 0.0002
HF	< 0.0012	< 0.013	< 0.014	< 0.0001	< 0.033	< 0.0002
LU	< 0.0003	< 0.0029	< 0.0032	< 0.0001	< 0.0078	< 0.0001
YB	< 0.0004	< 0.0043	< 0.0047	< 0.0001	< 0.011	< 0.0001
TM	< 0.0002	< 0.0026	< 0.0029	< 0.0001	< 0.0069	< 0.0001
ER	< 0.0007	< 0.0077	< 0.0084	< 0.0001	< 0.020	< 0.0001
HO	< 0.0002	< 0.0025	< 0.0028	< 0.0001	< 0.0067	< 0.0001
DY	< 0.0004	< 0.0044	< 0.0048	< 0.0001	< 0.012	< 0.0001
TB	< 0.0001	< 0.0012	< 0.0013	< 0.0001	< 0.0032	< 0.0001
GD	< 0.0004	< 0.0044	< 0.0048	< 0.0001	< 0.012	< 0.0001
EU	< 0.0002	< 0.0020	< 0.0022	< 0.0001	< 0.0052	< 0.0001
SM	< 0.0007	< 0.0076	< 0.0083	< 0.0001	< 0.020	< 0.0001
ND	< 0.0009	< 0.0095	< 0.0100	< 0.0001	< 0.025	< 0.0001
PR	< 0.0002	< 0.0017	< 0.0018	< 0.0001	< 0.0045	< 0.0001
CE	< 0.0021	< 0.0023	< 0.0044	< 0.0001	0.030	0.0002
LA	< 0.0002	< 0.0025	< 0.0027	< 0.0001	0.0100	< 0.0001
BA	< 0.022	< 0.24	< 0.26	< 0.0025	0.67	0.0040
CS	< 0.0001	< 0.0005	< 0.0006	< 0.0001	< 0.0020	< 0.0001
I	< 0.0006	< 0.0065	< 0.0072	< 0.0001	< 0.017	< 0.0001
TE	< 0.0005	< 0.0055	< 0.0060	< 0.0001	< 0.015	< 0.0001
SB	< 0.0010	0.0039	0.0039	< 0.0001	< 0.029	< 0.0002
SN	0.014	< 0.073	0.014 TO 0.073	0.0001 TO 0.0007	0.15	0.0009
CD	0.0059	0.71	0.72	0.0069	0.38	0.0023
PD	< 0.0005	< 0.0055	< 0.0060	< 0.0001	< 0.014	< 0.0001
RH	< 0.0002	< 0.0019	< 0.0021	< 0.0001	< 0.0051	< 0.0001

Site 302

TABLE F-8 (continued).

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0007	< 0.0070	< 0.0077	< 0.0001	< 0.019	< 0.0001
MO	0.0035	0.023	0.026	0.0002	0.018	0.0001
NB	< 0.0001	< 0.0008	< 0.0009	< 0.0001	< 0.0022	< 0.0001
ZR	< 0.020	< 0.0031	< 0.023	< 0.0002	0.028	0.0002
Y	< 0.0001	< 0.0013	< 0.0014	< 0.0001	< 0.0033	< 0.0001
SR	0.0053	< 0.16	0.0053 TO 0.16	< 0.0001 TO 0.0015	0.044	0.0003
RB	0.0013	< 0.0081	0.0013 TO 0.0081	< 0.0001 TO 0.0001	0.0036	< 0.0001
BR	< 0.0029	< 0.098	< 0.100	< 0.0010	0.090	0.0005
SE	< 0.0011	< 0.0037	< 0.0048	< 0.0001	< 0.021	< 0.0001
AS	< 0.0029	< 0.063	< 0.066	< 0.0006	0.041	0.0002
GE	< 0.0002	< 0.0026	< 0.0029	< 0.0001	< 0.0070	< 0.0001
GA	< 0.0001	< 0.0011	< 0.0012	< 0.0001	< 0.0028	< 0.0001
ZN	< 1.2	2.2	2.2	0.022	1.3	0.0081
CU	0.74	0.61	1.4	0.013	1.2	0.0071
NI	0.19	0.72	0.91	0.0087	15.	0.088
CO	< 0.0035	< 0.022	< 0.026	< 0.0002	0.049	0.0003
FE	0.98	< 1.8	0.98	0.0094	< 10.	< 0.060
MN	0.024	< 0.14	0.024 TO 0.14	0.0002 TO 0.0013	0.16	0.0010
CR	0.059	< 0.13	0.059 TO 0.13	0.0006 TO 0.0012	< 1.1	< 0.0064
V	< 0.0030	< 0.031	< 0.034	< 0.0003	< 0.083	< 0.0005
TI	0.044	0.055	0.099	0.0009	0.069	0.0004
CA	< 1.6	25.	25.	0.24	< 4.4	< 0.026
K	< 1.3	< 2.9	< 4.1	< 0.040	< 3.6	< 0.022
CL	< 0.48	1.2	1.2	0.012	< 20.	< 0.12
S	31.	28.	59.	0.57	29.	0.18
P	< 0.24	0.96	0.96	0.0092	< 2.4	< 0.014
SI	3.7	< 9.8	3.7 TO 9.8	0.035 TO 0.094	< 5.5	< 0.032
AL	< 0.85	MC	-	-	< 2.4	< 0.014
MG	< 0.52	1.4	1.4	0.014	1.5	0.0091
NA	MC	< 11.	-	-	< 9.3	< 0.056
F	< 0.015	< 0.048	< 0.063	< 0.0006	< 0.043	< 0.0003
B	< 0.17	< 0.018	< 0.19	< 0.0019	< 0.023	< 0.0001
BE	< 0.0001	< 0.0005	< 0.0005	< 0.0001	< 0.0004	< 0.0001
LI	< 0.0012	< 0.0056	< 0.0068	< 0.0001	0.015	< 0.0001

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.

TABLE F-9. SSMS ANALYTICAL DATA: SITE 303

ELEMENT	FILTER CATCH (MG)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0006	< 0.035	< 0.0006
TH	< 0.0009	< 0.051	< 0.0008
BI	0.0009	< 0.016	< 0.0002
PB	1.5	0.71	0.011
TL	< 0.0003	< 0.020	< 0.0003
AU	< 0.0004	< 0.027	< 0.0004
IR	< 0.0007	< 0.041	< 0.0006
OS	< 0.0008	< 0.044	< 0.0007
RE	< 0.0005	< 0.028	< 0.0004
W	< 0.0006	< 0.038	< 0.0006
HF	< 0.0008	< 0.047	< 0.0007
LU	< 0.0002	< 0.011	< 0.0002
YB	< 0.0003	< 0.016	< 0.0002
TM	< 0.0002	< 0.0098	< 0.0002
ER	< 0.0005	< 0.029	< 0.0005
HO	< 0.0002	< 0.0094	< 0.0001
DY	< 0.0003	< 0.016	< 0.0003
TB	< 0.0001	< 0.0045	< 0.0001
GD	< 0.0003	< 0.016	< 0.0003
EU	< 0.0001	< 0.0074	< 0.0001
SM	< 0.0005	< 0.029	< 0.0004
ND	0.0007	< 0.12	< 0.0019
PR	0.0001	0.0066	0.0001
CE	< 0.0015	0.030	0.0005
LA	< 0.0011	0.020	0.0003
BA	< 0.045	0.44	0.0070
CS	< 0.0002	< 0.0020	< 0.0001
I	< 0.0004	< 0.024	< 0.0004
TE	< 0.0003	< 0.021	< 0.0003
SB	< 0.0069	0.020	0.0003
SN	0.012	< 0.020	< 0.0003
CD	0.017	0.089	0.0014
PD	< 0.0003	< 0.021	< 0.0003
RH	< 0.0001	< 0.0072	< 0.0001

Site 303

TABLE F-9 (continued).

ELEMENT	FILTER CATCH (MG)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0004	< 0.026	< 0.0004
MO	0.0033	0.052	0.0008
NB	< 0.0002	0.0032	< 0.0001
ZR	0.021	0.058	0.0009
Y	0.0006	< 0.0047	< 0.0001
SR	0.013	0.062	0.0010
RB	0.0018	0.050	0.0008
BR	< 0.013	0.15	0.0020
SE	< 0.0100	< 0.19	< 0.0030
AS	0.0025	0.041	0.0007
GE	< 0.0002	< 0.0098	< 0.0002
GA	< 0.0001	< 0.0040	< 0.0001
ZN	5.4	1.3	0.020
CU	1.7	2.1	0.034
NI	0.95	8.3	0.13
CU	< 0.0071	< 0.062	< 0.0010
FE	< 2.4	< 10.	< 0.16
MN	0.12	0.27	0.0043
CR	0.092	0.55	0.0087
V	0.0020	< 0.053	< 0.0008
TI	0.13	0.69	0.011
CA	< 1.5	< 6.2	< 0.099
K	< 1.3	< 3.6	< 0.057
CL	2.2	< 9.0	< 0.14
S	31.	170.	2.7
P	0.51	< 2.2	< 0.036
SI	< 6.3	< 57.	< 0.90
AL	< 1.7	< 10.	< 0.16
MG	< 1.1	3.1	0.049
NA	< 2.3	< 13.	< 0.21
F	< 0.0100	< 0.027	< 0.0004
B	< 0.39	< 0.049	< 0.0008
BE	< 0.0001	< 0.0043	< 0.0001
LI	< 0.0036	< 0.014	< 0.0002

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.

TABLE F-10. SSMS ANALYTICAL DATA: SITE 304

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0010	< 0.0019	< 0.0029	< 0.0001	< 0.025	< 0.0004
TH	< 0.0014	< 0.0028	< 0.0042	< 0.0001	< 0.036	< 0.0005
BI	< 0.0004	< 0.0009	< 0.0013	< 0.0001	< 0.023	< 0.0003
PB	< 0.28	< 0.038	< 0.32	< 0.0059	1.7	0.026
TL	< 0.0005	< 0.0011	< 0.0016	< 0.0001	< 0.014	< 0.0002
AU	< 0.0007	< 0.0015	< 0.0022	< 0.0001	< 0.019	< 0.0003
IR	< 0.0011	< 0.0022	< 0.0033	< 0.0001	< 0.029	< 0.0004
OS	< 0.0012	< 0.0024	< 0.0036	< 0.0001	< 0.031	< 0.0005
RE	< 0.0008	< 0.0015	< 0.0023	< 0.0001	< 0.020	< 0.0003
W	< 0.0010	< 0.0021	< 0.0031	< 0.0001	< 0.026	< 0.0004
HF	< 0.0013	< 0.0026	< 0.0038	< 0.0001	< 0.033	< 0.0005
LU	< 0.0003	< 0.0006	< 0.0009	< 0.0001	< 0.0077	< 0.0001
YB	< 0.0004	< 0.0009	< 0.0013	< 0.0001	< 0.011	< 0.0002
TM	< 0.0003	< 0.0005	< 0.0008	< 0.0001	< 0.0069	< 0.0001
ER	< 0.0008	< 0.0016	< 0.0023	< 0.0001	< 0.020	< 0.0003
HO	< 0.0002	< 0.0005	< 0.0008	< 0.0001	< 0.0066	< 0.0001
DY	< 0.0004	< 0.0009	< 0.0013	< 0.0001	< 0.012	< 0.0002
TB	< 0.0001	< 0.0003	< 0.0004	< 0.0001	< 0.0031	< 0.0001
GD	< 0.0004	< 0.0009	< 0.0013	< 0.0001	< 0.011	< 0.0002
EU	< 0.0002	< 0.0004	< 0.0006	< 0.0001	< 0.0052	< 0.0001
SM	< 0.0008	< 0.0016	< 0.0023	< 0.0001	< 0.020	< 0.0003
ND	< 0.0010	< 0.0020	< 0.0029	< 0.0001	0.042	0.0006
PR	< 0.0002	< 0.0011	< 0.0013	< 0.0001	0.015	0.0002
CE	< 0.0016	< 0.0098	< 0.011	< 0.0002	0.21	0.0032
LA	< 0.0005	0.0018	0.0018	< 0.0001	0.068	0.0010
BA	< 0.051	< 0.069	< 0.12	< 0.0022	1.4	0.021
CS	0.0012	< 0.0012	0.0012	< 0.0001	< 0.0020	< 0.0001
I	< 0.0007	< 0.0013	< 0.0020	< 0.0001	< 0.017	< 0.0003
TE	< 0.0006	< 0.0011	< 0.0017	< 0.0001	< 0.014	< 0.0002
SB	< 0.0011	< 0.011	< 0.012	< 0.0002	0.68	0.0100
SN	< 0.032	< 0.032	< 0.063	< 0.0012	< 0.014	< 0.0002
CD	< 0.0007	< 0.029	< 0.030	< 0.0005	0.89	0.013
PD	< 0.0005	< 0.0011	< 0.0017	< 0.0001	< 0.014	< 0.0002
RH	< 0.0002	< 0.0004	< 0.0006	< 0.0001	< 0.0050	< 0.0001

TABLE F-10 (continued).

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0007	< 0.0014	< 0.0022	< 0.0001	< 0.018	< 0.0003
MO	0.0072	< 0.028	0.0072 TO 0.028	0.0001 TO 0.0005	0.27	0.0040
NB	< 0.0001	< 0.0035	< 0.0036	< 0.0001	0.023	0.0003
ZR	0.014	0.014	0.028	0.0005	0.028	0.0004
Y	< 0.0001	< 0.0003	< 0.0004	< 0.0001	< 0.0033	< 0.0001
SR	0.0033	< 0.032	0.0033 TO 0.032	< 0.0001 TO 0.0006	0.14	0.0022
RB	0.0019	< 0.0025	0.0019	< 0.0001	0.016	0.0002
BR	< 0.015	< 0.042	< 0.057	< 0.0011	0.055	0.0008
SE	< 0.0004	< 0.0034	< 0.0037	< 0.0001	0.066	0.0010
AS	0.0031	< 0.0003	0.0031	< 0.0001	0.13	0.0020
GE	< 0.0003	< 0.0005	< 0.0008	< 0.0001	< 0.0069	< 0.0001
GA	< 0.0001	< 0.0069	< 0.0070	< 0.0001	< 0.0028	< 0.0001
ZN	0.93	< 0.37	0.93	0.017	4.0	0.061
CU	0.79	< 0.49	0.79	0.015	9.7	0.15
NI	0.64	< 0.70	0.64	0.012	8.7	0.13
CO	0.0077	< 0.0075	0.0077	0.0001	0.22	0.0033
FE	8.2	< 0.37	8.2	0.15	71.	1.1
MN	0.049	< 0.029	0.049	0.0009	1.1	0.017
CR	0.022	< 0.058	0.022 TO 0.058	0.0004 TO 0.0011	0.95	0.014
V	0.0038	< 0.0019	0.0038	< 0.0001	0.16	0.0023
CA	< 0.72	< 16.	< 17.	< 0.32	< 19.	< 0.28
K	< 0.96	< 0.42	< 1.4	< 0.026	< 11.	< 0.17
CL	0.21	< 1.5	0.21 TO 1.5	0.0039 TO 0.029	< 4.4	< 0.067
S	11.	< 25.	11. TO 25.	0.20 TO 0.47	290.	4.3
P	< 0.19	< 0.53	< 0.72	< 0.013	< 2.4	< 0.036
SI	22.	< 6.7	22.	0.41	< 26.	< 0.39
AL	0.74	< 0.55	0.74	0.014	33.	0.50
MG	< 0.37	< 2.5	< 2.9	< 0.054	2.1	0.032
NA	< 1.1	< 2.2	< 3.2	< 0.060	< 28.	< 0.42
B	0.51	< 0.013	0.51	0.0094	< 0.072	< 0.0011
BE	< 0.0002	< 0.0001	< 0.0001 TO 0.0002	< 0.0001 TO 0.0001	0.0039	< 0.0001
LI	< 0.0038	< 0.0026	< 0.0064	< 0.0001	0.013	0.0002

TABLE F-11. SSMS ANALYTICAL DATA: SITES 326 AND 327

	SITE 326-1:		SITE 326-2:		SITE 327-1:	
ELEMENT	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.14	< 0.0054	< 0.14	< 0.0043	< 0.38	< 0.016
TH	< 0.21	< 0.0078	< 0.20	< 0.0062	< 0.55	< 0.024
BI	< 0.064	< 0.0024	< 0.063	< 0.0019	< 1.4	< 0.060
PB	4.4	0.17	2.2	0.067	< 0.99	< 0.042
TL	< 0.080	< 0.0030	< 0.079	< 0.0024	< 0.21	< 0.0091
AU	< 0.11	< 0.0040	< 0.11	< 0.0032	< 0.28	< 0.012
IR	< 0.16	< 0.0062	< 0.16	< 0.0049	< 0.44	< 0.019
OS	< 0.18	< 0.0067	< 0.18	< 0.0054	< 0.48	< 0.020
RE	< 0.11	< 0.0043	< 0.11	< 0.0034	< 0.30	< 0.013
W	< 0.43	< 0.016	< 1.2	< 0.038	1.7	0.071
HF	< 0.19	< 0.0071	< 0.19	< 0.0057	< 0.50	< 0.022
LU	< 0.044	< 0.0017	< 0.044	< 0.0013	< 0.12	< 0.0050
YB	< 0.065	< 0.0024	< 0.063	< 0.0019	< 0.17	< 0.0073
TM	< 0.039	< 0.0015	< 0.039	< 0.0012	< 0.11	< 0.0045
ER	< 0.12	< 0.0044	< 0.11	< 0.0035	< 0.31	< 0.013
HO	< 0.038	< 0.0014	< 0.037	< 0.0011	< 0.100	< 0.0043
DY	< 0.066	< 0.0025	< 0.065	< 0.0020	< 0.18	< 0.0075
TB	< 0.018	< 0.0007	< 0.018	< 0.0005	< 0.048	< 0.0020
GD	< 0.066	< 0.0025	< 0.065	< 0.0020	< 0.18	< 0.0075
EU	< 0.030	< 0.0011	< 0.029	< 0.0009	< 0.080	< 0.0034
SM	< 0.12	< 0.0043	< 0.11	< 0.0035	< 0.31	< 0.013
ND	< 0.14	< 0.0054	< 0.14	< 0.0043	< 0.38	< 0.016
PR	< 0.025	< 0.0009	< 0.025	< 0.0008	< 0.068	< 0.0029
CE	< 0.068	< 0.0025	< 0.034	< 0.0010	< 0.091	< 0.0039
LA	< 0.037	< 0.0014	< 0.037	< 0.0011	< 0.099	< 0.0042
BA	0.14	0.0054	0.29	0.0089	17.	0.71
CS	< 0.0060	< 0.0002	< 0.0059	< 0.0002	< 0.016	< 0.0007
I	< 0.099	< 0.0037	< 0.097	< 0.0030	< 0.26	< 0.011
TE	< 0.083	< 0.0031	< 0.082	< 0.0025	< 0.22	< 0.0095
SB	< 0.058	< 0.0022	< 0.057	< 0.0017	< 0.15	< 0.0066
SN	< 0.16	< 0.0058	< 0.080	< 0.0025	0.83	0.035
CD	< 0.100	< 0.0038	< 0.100	< 0.0031	0.55	0.023
PD	< 0.083	< 0.0031	< 0.081	< 0.0025	< 0.22	< 0.0094
RH	< 0.029	< 0.0011	< 0.026	< 0.0009	< 0.077	< 0.0033

TABLE F-11 (continued).

	SITE 326-1:		SITE 326-2:		SITE 327-1:	
ELEMENT	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.11	< 0.0040	< 0.100	< 0.0032	< 0.28	< 0.012
MO	< 0.28	< 0.0100	< 1.1	< 0.034	< 0.52	< 0.022
NB	< 0.035	< 0.0013	< 0.034	< 0.0010	< 0.033	< 0.0014
ZR	< 0.046	< 0.0017	< 0.046	< 0.0014	< 0.12	< 0.0053
Y	< 0.019	< 0.0007	< 0.019	< 0.0006	< 0.051	< 0.0022
SR	0.098	0.0037	0.065	0.0020	0.26	0.011
RB	0.012	0.0004	< 0.0080	< 0.0002	0.043	0.0018
BR	< 0.21	< 0.0077	0.39	0.012	0.55	0.023
SE	< 0.47	< 0.018	< 0.055	< 0.0017	< 0.30	< 0.013
AS	< 0.089	< 0.0033	< 0.043	< 0.0013	< 0.12	< 0.0050
GE	< 0.040	< 0.0015	< 0.039	< 0.0012	< 0.11	< 0.0045
GA	< 0.016	< 0.0006	< 0.016	< 0.0005	< 0.24	< 0.0100
ZN	6.4	0.24	< 4.3	< 0.13	1.4	0.059
CU	19.	0.73	4.4	0.14	4.5	0.19
NI	2.8	0.100	< 3.1	< 0.096	< 6.1	< 0.26
CO	0.052	0.0020	< 0.091	< 0.0028	< 0.17	< 0.0074
FE	< 25.	< 0.95	< 18.	< 0.54	< 24.	< 1.0
MN	< 0.86	< 0.032	< 0.84	< 0.026	0.98	0.042
CR	0.84	0.031	< 1.6	< 0.050	< 0.85	< 0.036
V	< 0.23	< 0.0085	< 0.44	< 0.014	< 1.7	< 0.072
TI	< 0.53	< 0.020	< 0.36	< 0.011	< 0.35	< 0.015
CA	< 14.	< 0.54	< 5.1	< 0.16	< 19.	< 0.82
K	6.8	0.25	5.6	0.17	< 19.	< 0.82
S	220.	8.4	270.	8.1	560.	24.
P	4.0	0.15	1.5	0.047	< 2.3	< 0.096
SI	< 10.	< 0.38	< 5.0	< 0.15	< 37.	< 1.6
AL	7.5	0.28	2.8	0.086	6.5	0.28
MG	0.83	0.031	< 2.4	< 0.075	10.	0.45
NA	51.	1.9	14.	0.43	140.	5.9
B	< 0.11	< 0.0041	< 0.15	< 0.0046	< 0.099	< 0.0042
BE	0.072	0.0027	0.071	0.0022	< 0.018	< 0.0008
LI	0.040	0.0015	< 0.025	< 0.0008	0.052	0.0022

TABLE F-12. DISTRIBUTION OF VOLATILE (C_8-C_{12}) AND NONVOLATILE (> C_{16}) ORGANICS IN SASS TRAIN SAMPLES: GAS-FIRED SOURCES

Sample type	Site	Volatile (mg/m^3)	Nonvolatile (mg/m^3)
Solvent probe rinse (PR-O)	100	< 0.01	0
	101	< 0.01	0.14
	102	-	0.031
	103	0.36	0.03
	104	< 0.01	0
Solvent XAD-2 module rinse (MR-O)	100	< 0.01	0.18
	101	< 0.01	0.81
	102	-	0.47
	103	< 0.01	0.27
	104	< 0.01	0.86
XAD-2 resin - solvent extract (XR-SE)	100	2.11	0.22
	101	< 0.01	0.29
	102	-	0.28
	103	1.09	0.18
	104	5.01	0.06

TABLE F-13. DISTRIBUTION OF VOLATILE (C_8-C_{12}) AND NONVOLATILE (> C_{16}) ORGANICS BY GAS-FIRED SITE

Site	Sample type	Volatile (mg/m^3)	Nonvolatile (mg/m^3)	Total organics (mg/m^3)
100	PR-O	< 0.01	0.0	< 0.01
	MR-O	< 0.01	0.18	0.18
	XR-SE	2.11	0.22	2.33
101	PR-O	< 0.01	0.14	0.14
	MR-O	< 0.01	0.81	0.81
	XR-SE	< 0.01	0.24	0.24
102	PR-O	-	0.03	> 0.03
	MR-O	-	0.47	> 0.47
	XR-SE	-	0.28	> 0.28
103	PR-O	0.36	0.03	0.39
	MR-O	< 0.01	0.27	0.27
	XR-SE	1.09	0.18	1.27
104	PR-O	< 0.01	0.0	< 0.01
	MR-O	< 0.01	0.86	0.86
	XR-SE	5.01	0.06	5.07

TABLE F-14. DISTRIBUTION OF VOLATILE (C_7-C_{16}) AND NONVOLATILE (> C_{16}) ORGANICS IN SASS TRAIN SAMPLES: OIL-FIRED SOURCES*

Sample type	Site	Volatile		Nonvolatile		Volume of air sampled (m^3)
		Total μg	mg/m^3	Total μg	mg/m^3	
Solvent probe rinse (PR-O)	300	< 31†		< 1,000		91.9
	301	< 217		< 5,000		88.1
	302	< 140		< 13,000		104
	303	< 116		< 6,000		80.6
	304	< 285		114,000	1.49	76.7
Solvent XAD-2 module rinse (MR-O)	300	< 31		< 1,000		91.9
	301	644	0.0073	20,200	0.23	88.1
	302	< 140		< 13,000		104
	303	< 116		< 6,000		80.6
	304	< 285		14,900	0.19	76.7
Condensate - solvent extract (CD-LE)	300	< 300		15,600	0.17	91.9
	301	< 34		87,800	1.00	88.1
	302	1,880	0.021	< 2,000		104
	303	1,840	0.026	< 6,000		80.6
	304	< 341		92,700	1.21	76.7
XAD-2 resin - solvent extract (XR-SE)	300	15,500	0.17	43,000	0.47	91.9
	301	15,400	0.17	52,600	0.60	88.1
	302	56,600	0.54	30,200	0.29	104
	303	42,900	0.53	96,600	1.20	80.6
	304	24,600	0.32	237,000	3.09	76.7

---

*All values have been blank-corrected.

†All numbers reported as "less than" (<) are sample values found to be less than the blank value; number reported is value of blank.

TABLE F-15. DISTRIBUTION OF VOLATILE (C_7-C_{16}) AND NONVOLATILE (> C_{16}) ORGANICS BY OIL-FIRED SITE[*]

Site	Volume of air sampled (m^3)	Sample type	Volatile		Nonvolatile		Total organics	
			Total µg	mg/m^3	Total µg	mg/m^3	Total µg	mg/m^3
300	91.1	PR-O	< 31[†]		< 1,000			
		MR-O	< 31		< 1,000			
		CD-LE	< 300		15,600	0.170	15,600	0.17
		XR-SE	15,500	0.17	43,000	0.469	58,500	0.64
		XRB-SE	(3,370)		(4,000)			
		Totals	15,500	0.17	58,600	0.639	74,100	0.81
301	88.1	PR-O	< 217		< 5,000			
		MR-O	644	0.01	20,200	0.229	20,844	0.24
		CD-LE	< 34		87,800	0.997	87,800	1.00
		XR-SE	15,400	0.17	52,600	0.597	68,000	0.77
		XRB-SE	(1,670)		(22,400)			
		Totals	16,044	0.18	160,600	1.823	176,644	2.01
302	104	PR-O	< 140		< 13,000			
		MR-O	< 140		< 13,000			
		CD-LE	1,880	0.02	< 2,000		1,880	0.02
		XR-SE	56,600	0.54	30,200	0.290	86,800	0.83
		XRB-SE	(1,670)		(22,400)			
		Totals	58,480	0.56	30,200	0.290	88,680	0.85
303	80.6	PR-O	< 116		< 6,000			
		MR-O	< 116		< 6,000			
		CD-LE	1,840	0.03	< 6,000		1,840	0.03
		XR-SE	42,900	0.53	96,600	1.20	139,500	1.73
		XRB-SE	(9,230)		(6,930)			
		Totals	44,740	0.56	96,600	1.20	141,340	1.76
304	76.7	PR-O	< 285		114,000	1.49	114,000	1.49
		MR-O	< 285		14,900	0.194	14,900	0.19
		CD-LE	< 341		92,700	1.21	92,700	1.21
		XR-SE	24,600	0.32	237,000	3.09	261,600	3.41
		XRB-SE	(6,930)		(64,000)			
		Totals	24,600	0.32	458,600	5,984	483,200	6.30

---

[*] All values have been blank-corrected.

[†] All numbers reported as "less than" (<) are sample values found to be less than the blank value; number reported is value of blank.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-79-029b	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Emissions Assessment of Conventional Stationary Combustion Systems; Volume I. Gas- and Oil-fired Residential Heating Sources		5. REPORT DATE May 1979 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) N. F. Surprenant, R. R. Hall, K. T. McGregor, and A. S. Werner (GCA/Technology Division)		8. PERFORMING ORGANIZATION REPORT NO. GCA-TR-77-30-G(1)
9. PERFORMING ORGANIZATION NAME AND ADDRESS TRW, Inc. One Space Park Redondo Beach, California 90278		10. PROGRAM ELEMENT NO. EHE624A 11. CONTRACT/GRANT NO. 68-02-2197
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 9/76 - 3/79 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Ronald A. Venezia, MD-62, 919/541-2547.

16. ABSTRACT The report gives results of an assessment of emissions from gas- and oil-fired residential heating sources, through a critical examination of existing emissions data, followed by a phased measurement program to fill gaps in the emissions data base. Initially, five gas-fired and five oil-fired residential sources were tested. Mass emission rates of criteria pollutants, trace elements, and organics (including POM) were determined. Subsequent test program evaluation led to a decision to conduct additional tests at one gas-fired and two oil-fired sites, to determine the effect of the burner on/off cycle on emissions. Particulate, SO4, SO2, and SO3 emission data were also obtained at the oil-fired sites. Assessment results indicate that residential sources are of potential significance based on multiple source severity factors calculated for an array of homes burning gas or oil. Pollutants for which multiple source severity factors exceed 0.05 (the level which may be potentially significant) are: NOx from gas-fired sources, and SO3, NOx, and Ni from oil-fired sources. Measured criteria pollutant emission factors were generally comparable to EPA emission factors (in AP-42), except for total HC emissions from oil-fired sources which were 3 times greater. However, POM compounds known to be carcinogenic were not found above the detection limit of 0.3 micrograms/cubic meter.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Dust	Pollution Control	13B	11G
Assessments	Sulfur Oxides	Stationary Sources	14B	07B
Emission	Organic Compounds	Residential Furnaces		07C
Heating	Nitrogen Oxides	Particulate	13H, 13A	
Combustion	Hydrocarbons		21B	
Natural Gas			21D	
Fuel Oil				

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 176
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

EPA-600/7-79-029b **Emissions Assessment of Conventional Stationary Combustion Systems;**
Volume I. Gas- and Oil-fired Residential Heating Sources

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Environmental Research Information Center
Cincinnati, Ohio 45268

Publication No EPA-600/7-79-029b