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Project Summary

Emissions Assessment of Conventional Stationary Combustion Systems:

Volume III. External Combustion Sources for Electricity Generation

C. C. Shih, R. A. Orsini, D. G. Ackerman, R. Moreno, E. L. Moon, L. L. Scinto, and C. Yu

Multimedia emissions from external combustion sources for electricity generation are characterized in this study. In the assessment process, existing emissions data were first examined to determine the adequacy of the data base. This was followed by the conduct of a measurement program to fill the identified data gaps. Emissions data obtained from the sampling and analysis program were combined with existing emissions data to provide estimates of emission levels, and to define the need for additional data.

The results of this study indicate that external combustion sources for electricity generation contribute significantly to the nationwide emissions burden. Flue gas emissions of NO_x, SO_2, and particulate matter from these sources account for approximately 50 percent, 57 percent, and 25 percent, respectively, of the emissions of these pollutants from all stationary sources. Flue gas emissions of sulfates and several trace elements from coal- and oil-fired utility boilers also require further attention. POM compounds in flue gas emissions are mostly naphthalene, phenanthrene, and pyrene. Although, dibenz(a,h)anthracene and possibly benzo(a)pyrene, both active carcinogens, were also detected at a limited number of coal-fired sites.

A second major source of air emissions is vapors and drifts from cooling towers. Air emissions of chlorine, magnesium, phosphorus, and sulfates from mechanical draft cooling towers were found to be comparable to flue gas emissions of these pollutants from oil-fired utility boilers.

The multiple use of water in steam electric plants results in wastewater streams from several operations. In general, concentrations of iron, magnesium, manganese, nickel, and phosphorus are at levels that may be of environmental concern. Average organic levels ranged from 0.01 mg/l for ash pond effluents to 6.0 mg/l for boiler blowdown. No POM compounds were detected.

Data on coal fly ash and bottom ash show that from eleven to sixteen trace

elements are present at potentially harmful levels. The only POM compounds detected, however, were naphthalene, alkyl naphthalenes, and other relatively nontoxic compounds.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Emissions from external combustion sources for electricity generation are characterized in this study. According to the classification system in the current study, all fossil-fuel-fired boilers owned by public and private utilities to generate electricity are included in this source category.

For the purposes of this study, all major process operations and onsite facilities involved in the generation of power by utilities are covered in this source category. Support facilities and operations addressed in this report include: coal storage, cooling water systems, makeup water treatment, chemical cleaning of boiler tubes, air and water pollution control, and solid waste disposal. Fugitive emissions from ash handling and storage and fuel handling are not considered here.

Assessment Methodology

The phased approach to environmental assessment is designed to provide comprehensive emissions information on all process waste streams in a cost effective manner. To achieve this goal, two distinct sampling and analysis levels are being employed in this project. Level I utilizes semiquantitative (± a factor of 3) techniques of sample collection and laboratory and field analyses to: provide preliminary emissions data for waste streams and pollutants not adequately characterized; identify potential problem areas; and 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 contain significant pollutant loadings. The data developed at Level II are used to identify control technology needs and to further define the environmental hazard associated with each process stream.

The Existing Emissions Data Base

Decisions as to the adequacy of the existing data base were made using critieria developed by considering both the reliability and variability of the data. Estimated environmental risks associated with the emission of each pollutant were also considered in the determination of the need for, and extent of, the sampling and analysis program. For criteria pollutants, comparison of calculated maximum ground level concentrations with national primary ambient air quality standards was used as the basis for estimation of environmental risks. As a result of the data evaluation effort, a number of data inadequacies have been identified. For flue gas emissions, the status of the existing data base can be summarized as follows:

- The existing data base for criteria pollutants is generally adequate.
- For sulfuric acid emissions, the existing data base is adequate for bituminous-coal-fired boilers, residual-oil-fired boilers, and gas-fired boilers, but inadequate for lignite-fired boilers. For emissions of primary sulfates, the existing data base is adequate for pulverized bituminous dry bottom and wet bottom boilers, residual oil-fired boilers, gas-fired boilers, but inadequate for other combustion source categories.
- For emissions of particulates by size fraction and trace elements, the existing data base is adequate for gas-fired boilers but inadequate for all other combustion source categories.
- For emissions of specific organics and polycyclic organic matter (POM), the existing data base is inadequate for all combustion source categories.

Two other sources of air emissions of environmental concern are cooling tower emissions and emissions from coal storage piles. The existing data bases characterizing air emissions from these two sources are considered to be inadequate, because past studies were primarily focused on the measurements of a limited number of chemical constituents and total particulates.

For wastewater effluents from external combustion sources for electricity generation, the existing data base is considered to be adequate for wastewater from water treatment processes, and inadequate for all other streams. This is because past studies were limited to the characterization of gross parameters such as pH and total suspended solids (TSS) and a few inorganic constituents. Organic characterization data are generally not available.

The evaluation of existing emissions data for solid wastes indicated the inadequacy of the organic data base for coal fly ash and bottom ash, and the inadequacy of the inorganic and organic data bases for FGD sludges. On the other hand, the inorganic content for coal ash is considered to be adequately characterized.

Similarly, the data base for water treatment wastes is considered to be adequate, because the waste constituents are inorganic and can be estimated from the raw water constituents and the treatment method used.

The Source Measurement Program

Because of the deficiencies in the existing emissions data base, 46 sites were selected for sampling and analysis of flue gas emissions, and 6 sites were selected for sampling and analysis of air emissions from cooling towers. At a selected number of these sites, wastewater streams and solid wastes were also sampled and analyzed. Wastewater streams sampled and analyzed included cooling tower blowdown, once-through cooling water, boiler blowdown, fly ash pond overflow, bottom ash pond overflow, and combined ash pond overflow. Intermittent wastewater streams such as chemical cleaning wastes and coal pile runoff were not sampled. Solid waste streams sampled and analyzed included fly ash, bottom ash, and FGD scrubber sludge.

Sampling and Analysis Methodology

Level I Field Testing

The Source Assessment Sampling System (SASS) train, developed by EPA, was used to collect both vapor and particulate emissions in quantities sufficient for the wide range of analyses needed to adequately characterize emissions from external combustion sources.

In addition to using the SASS train for stack gas sampling, other equipment was employed to collect those components that could not be analyzed from the train samples. A gas chromatograph (GC) with flame ionization detection was used in the field to analyze hydrocarbons in the boiling point range of -160 to 90°C (reported as C_1-C_6) collected in gas sampling bags. These samples were also analyzed for CO, CO_2, O_2, and SO_2 by GC using a thermal conductivity detector.

Water samples were generally taken by either tap sampling or dipper sampling. Tap samples were obtained on contained liquids in motion or static liquids in tanks or drums. This sampling method was generally applicable to cooling tower blowdown or boiler blowdown. The dipper sampling procedure, applicable to sampling ponds or open discharge streams, was used in the acquisition of ash pond discharge samples. After sample recovery, water analyses using the Hach kit were performed in the field to determine pH, conductivity, total suspended solids (TSS), hardness, alkalinity or acidity, ammonia nitrogen, cyanide, nitrate nitrogen, phosphate, sulfite and sulfate.

For solids sampling, the fractional shovel grab samples procedure was used unless the plant had an automatic sampling system. The concept of fractional shoveling involves the acquisition of a time-integrated grab sample representative of overall process input or output during a given run time period. When plants were equipped with automatic samplers to remove representative cross sections of a stream while automatically forming a homogeneous composite, these were used in preference to the shovel technique.

In addition to the above sampling methods, sampling for air emissions from cooling towers was performed using a modified EPA Method 5 train without the filter assembly.

Modified Level I Laboratory Analysis

The basic Level I schematic outlining flow of samples and analysis plans for particulate and gaseous emissions is depicted in Figure 1. The corresponding schematic for solid, slurry, and liquid samples is presented in Figure 2. Details of the sample handling, transfer, and analysis procedures can be found in the *IERL-RTP Procedures Manual: Level I Environmental Assessment*, EPA-600/2-76-160a (NTIS PB 257 850), now superceded.

Inorganic Analyses

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

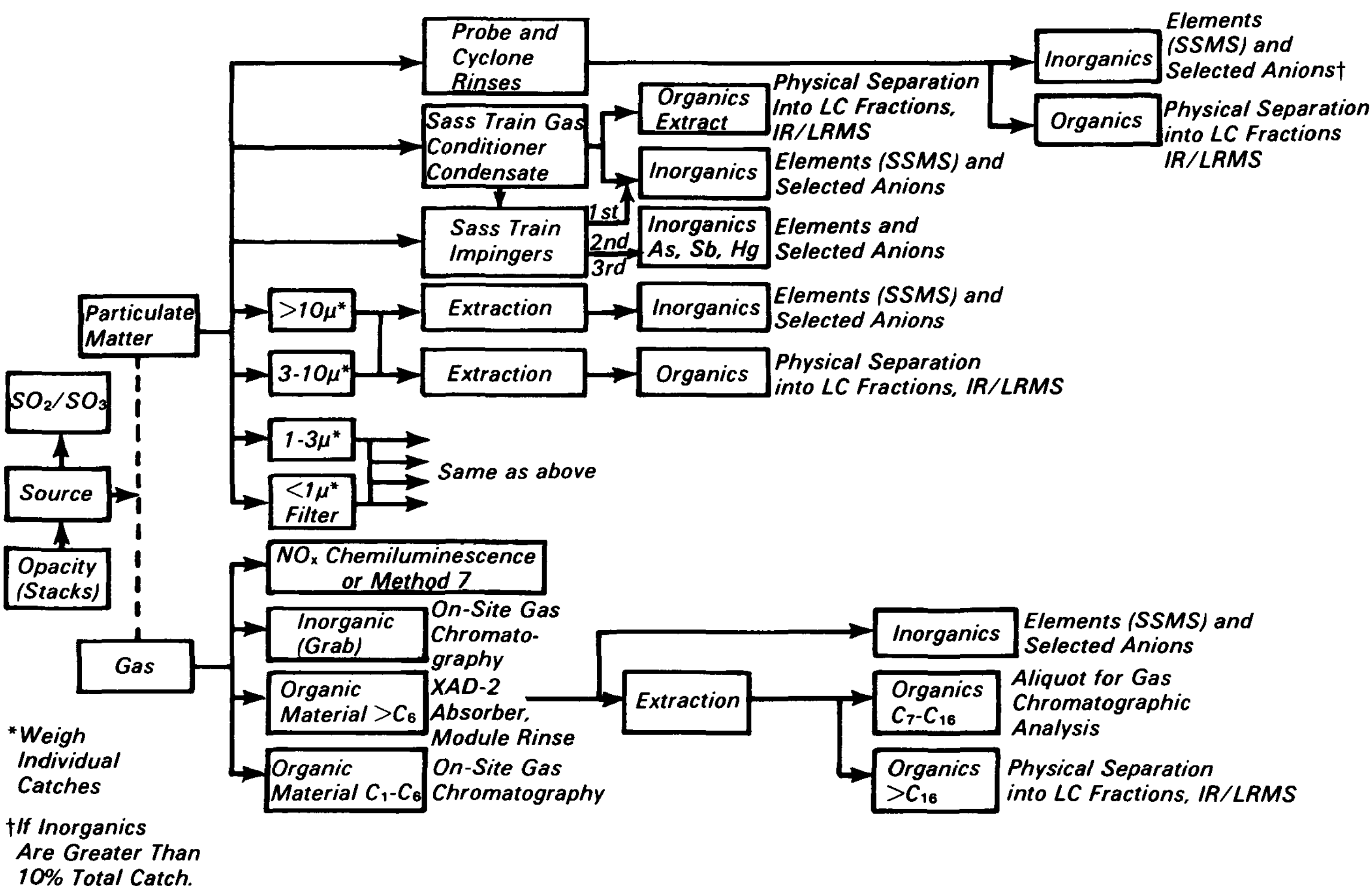

Figure 1. *Basic Level 1 sampling flow and analytical plan for particulates and gases.*

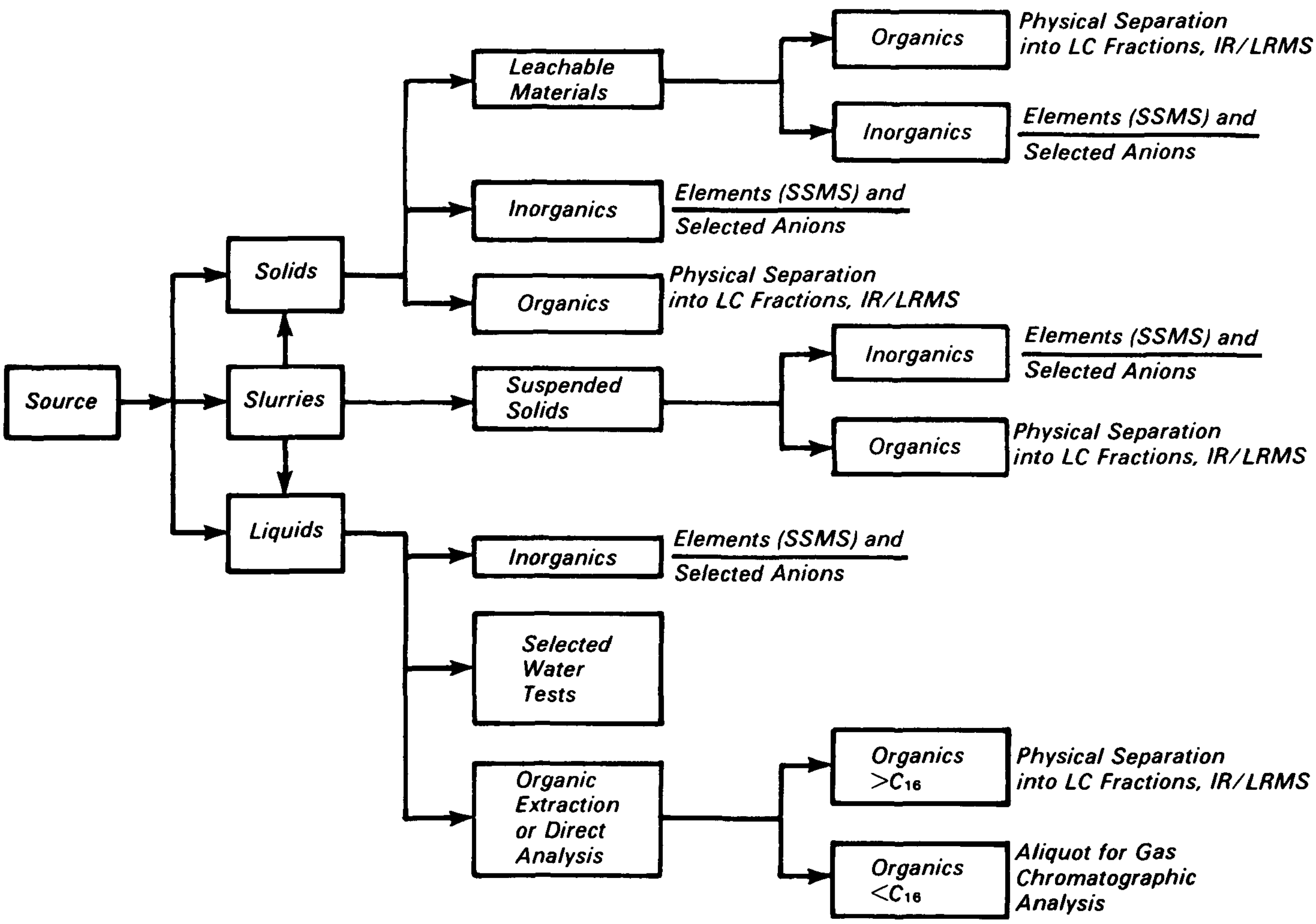

Figure 2. *Basic Level 1 sampling flow and analytical scheme for solids, slurries and liquids.*

Spectrometer (SSMS). SSMS data were supplemented with Atomic Absorption Spectrometry (AAS) data for Hg, As, and Sb and with specific ion electrode determinations for chlorides.

The following SASS train fractions were analyzed for their elemental composition: 1) the particulate filter, 2) the XAD-2 sorbent, and 3) a composite sample containing portions of the XAD-2 module condensate and HNO_3 rinse, and the first impinger solution. Analyses of the carbon, hydrogen, nitrogen, oxygen, and trace element contents and heating values of the fuel were also performed for the coal-fired and oil-fired sources.

Organic Analyses

Level I organic analysis provides data on volatile (boiling point range of 90 to 300°C, corresponding to the boiling points of C_7-C_{16} n-alkanes and reported as C_7-C_{16}) and non-volatile organic compounds (boiling point >300°C, corresponding to the boiling points of $>C_{16}$ n-alkanes and reported as $>C_{16}$) to supplement data for gaseous organics (boiling point range of −160 to 90°C, corresponding to the boiling points of C_1-C_6 n-alkanes and reported as C_1-C_6) measured in the field. Organics in the XAD-2 module condensate trap and XAD-2 resin were recovered by methylene chloride extraction. SASS train components including the tubing were carefully cleaned with methylene chloride or methylene chloride/methanol solvent to recover all organics collected.

Because all samples were too dilute to detect organic compounds by the majority of instrumental techniques employed, the first step in the analysis was to concentrate the sample fractions from as much as 1000 ml to 10 ml in a Kuderna-Danish apparatus in which rinse solvent is evaporated while the organics of interest are retained*. Kuderna-Danish concentrates were then evaluated by gas chromatography (GC), infrared spectrometry (IR), liquid chromatography (LC), gravimetric analysis, low resolution mass spectroscopy (LRMS), and sequential gas chromatography/mass spectrometry (GC/MS)†. The extent of the organic analysis was determined by the stack gas concentrations found for total organics (volatile and non-volatile). If the total organics indicated a stack gas concentration below 500 ug/m³, a liquid concentration below 0.1 mg/l, or a solid concentration below 1 mg/kg, further analysis was

*Kuderna-Danish is a glass apparatus for evaporating bulk amount of solvents.
†The major modification in the Level I sampling and analysis procedure was the addition of GC/MS analysis for POM.

not conducted. If the concentrations were above these levels, a class fractionation by liquid chromatography was conducted followed by GC and IR analyses. If the concentrations in a LC fraction were above these levels, LRMS were conducted for that particular LC fraction.

Conclusions

Characteristics of Flue Gas Emissions

The results of the field measurements for flue gas emissions from utility boilers, along with supplementary values for certain pollutants obtained from the existing data base, are presented in Tables 1, 2, and 3.

Criteria Pollutants—

- Emissions of NO_x from external combustion sources for electricity generation are a significant environmental problem. These emissions account for approximately 50 percent of the total NO_x emissions from all stationary sources. Of the NO_x emissions from external combustion sources for electricity generation, 77 percent are contributed by burning of bituminous coal. Source severity factors for NO_x emissions from utility boilers range from 0.13 for bituminous coal-fired stokers to 6.4 for bituminous coal-fired cyclone boilers.
- Emissions of SO_2 from external combustion sources for electricity generation contribute significantly to the national emissions burden. These emissions account for approximately 57 percent of the total SO_2 emissions from all stationary sources. Approximately 88 percent of the SO_2 emissions from external combustion sources for electricity generation are contributed by burning of bituminous coal. Source severity factors for uncontrolled SO_2 emissions range from 0.0007 for natural gas, wall-fired boilers to 3.3 for bituminous coal-fired cyclone boilers.
- Emissions of particulates from external combustion sources for electricity generation, despite the widespread application of control devices, are still a significant environmental problem. These emissions account for approximately 25 percent of the total particulate emissions from all stationary sources. Almost all (95 percent) particulate emissions from external combustion sources for electricity generation are contributed by burning of bituminous coal. Source severity factors for particulate emissions range from 0.001 for natural gas, wall-fired boilers to 0.74 for lignite-fired cyclone boilers.
- Emissions of total hydrocarbons from external combustion sources for electricity generation contribute approximately 4 percent of the total emissions of these pollutants from all stationary sources. Source severity factors for emissions of total hydrocarbons range from 0.005 to 0.12.
- Emissions of CO from external combustion sources for electricity generation are not an environmental concern. Source severity factors for CO emissions are all well below 0.05. Total CO emissions from these sources account for approximately 0.6 percent of CO emissions from all stationary sources.

Table 1. *Summary of Assessment Results for Flue Gas Emissions from Bituminous Coal-Fired Utility Boilers*

Pollutant	Pulverized Dry Bottom		Pulverized Wet Bottom		Cyclone		Stokers	
	Emission Factor (ng/J)	Source Severity Factor	Emission Factor (ng/J)	Source Severity Factor	Emission Factor (ng/J)	Source Severity Factor	Emission Factor (ng/J)	Source Severity Factor
NO_x	259*, 379†	1.95*, 2.85†	380	1.70	678	6.36	241	0.13
Total Hydrocarbons	4.5	0.027	4.5	0.016	9.5	0.072	11	0.0048
CO	17	0.0005	86	0.0015	82	0.0030	157	0.0003
Particulates (Controlled)	251	0 66	213	0.33	57	0.19	603	0.12
SO_2 (Uncontrolled)	1,407	2.64	1,407	1.57	1,407	3.29	1,407	0.19
SO_3	13.9	3.50	13.9	2.09	14.1	4.45	13.9	0.26
Particulate Sulfate (Controlled)	0.72	0.15	2.9	0.37	10.8	2.84	10.5	0.16
Trace Elements‡								
Aluminum	8.5	0.53	6.9	0 16	1.4	0.071	2.6	0.008
Beryllium	0.0022	0.23	0 0018	0.11	0.00037	0.048	0.0055	0.041
Calcium	5.6	0.12	4.6	0.056	0.95	0.025	2.6	0.004
Chlorine	33.9	1.03	33.9	0.61	33.9	1.28	33.9	0.075
Fluorine	4.1	0.34	4.1	0.20	4.1	0.42	4.1	0.024
Iron	8.4	0.22	6.8	0.11	1.4	0.047	20.9	0.040
Lead	0.039	0.053	0.031	0.026	0.0066	0.011	0.61	0.061
Lithium	0.024	0.23	0.020	0.11	0.0041	0.048	0.011	0.008
Nickel	0.062	0.13	0.050	0.60	0.011	0.027	1.4	0.211
Phosphorus	0.11	0.22	0.086	0.11	0.018	0.046	0.55	0.083
Silicon	15.2	0.31	12.4	0.15	2.6	0.066	8.7	0.013
POM								
Dibenz(a,h)anthracene	0.00022	0.50	BD	NA	BD	NA	BD	NA
Benzo(a)pyrene/Benzo(e)pyrene	BD	NA	0.0035	21	BD	NA	BD	NA
Total POM	0.0039	NA	0 042	NA	0.0059	NA	0.015	NA

BD - Below detection limit. Detection limit for POM was 0.3 μg/m³ or approximately 0.0001 ng/J.
NA - Not applicable.
**For tangentially-fired pulverized bituminous dry bottom boilers.*
†For wall-fired pulverized bituminous dry bottom boilers.
‡For pulverized dry bottom, pulverized wet bottom, and cyclone boilers, the trace element emission factors presented are for units equipped with electrostatic precipitators. For stokers, the trace element emission factors presented are for units equipped with multiclones.

Table 2. *Summary of Assessment Results for Flue Gas Emissions from Lignite-Fired Utility Boilers*

Pollutant	Pulverized Dry Bottom		Cyclone		Stokers	
	Emission Factor (ng/J)	Source Severity Factor	Emission Factor (ng/J)	Source Severity Factor	Emission Factor (ng/J)	Source Severity Factor
NO_x	260	4.28	333	5.33	195	0.14
Total Hydrocarbons	9.0	0.12	4.7	0.061	4.4	0.002
CO	33	0.002	33	0.002	65	0.0002
Particulates (Controlled)	62	0.36	132	0.74	615	0.15
SO_2 (Uncontrolled)	628	2.57	628	2.50	628	0.11
SO_3	ND	ND	ND	ND	ND	ND
Particulate Sulfate (Controlled)	0.82	0.38	0.49	0.22	47.6	0.93
Trace Elements*						
Aluminum	0.068	0.006	<0.067	<0.006	15.2	0.056
Barium	<0.025	<0.023	<0.037	<0.032	2.0	0.076
Beryllium	<0.001	<0.23	<0.0003	<0.066	0.0059	0.057
Calcium	0.39	0.017	<1.5	<0.067	<140	<0.27
Copper	<0.030	<0.068	0.013	0.029	0.083	0.008
Fluorine	0.24	0.044	0.80	0.14	0.42	0.003
Magnesium	<0.22	<0.016	<0.16	<0.011	<27	<0.085
Nickel	<0.068	<0.31	<0.047	<0.21	.28	0.053
Phosphorus	<0.034	<0.16	<0.013	<0.055	.5	0.30
POM						
Biphenyl	BD	NA	0.00002	<0.0001	BD	NA
Trimethyl propenyl naphthalene	0.0033	0.0001	0.00034	<0 0001	0.0032	<0.0001

ND - No data.
BD - Below detection limit. Detection limit for POM was 0.3 μg/m³ or approximately 0.0001 ng/J.
NA - Not applicable.
*For pulverized dry bottom and cyclone boilers, the trace element emission factors presented are for units equipped with electrostatic precipitators. For stokers, the trace element emission factors presented are for units equipped with multiple cyclones.

Table 3. *Summary of Assessment Results for Flue Gas Emissions from Residual Oil- and Gas-Fired Utility Boilers*

Pollutant	Residual Oil				Natural Gas			
	Tangential Firing		Wall Firing		Tangential Firing		Wall Firing	
	Emission Factor (ng/J)	Source Severity Factor	Emission Factor (ng/J)	Source Severity Factor	Emission Factor (ng/J)	Source Severity Factor	Emission Factor (ng/J)	Source Severity Factor
NO_x	114	1.90	190	1.17	124	3.21	233	2.94
Total Hydrocarbons	4.6	0.060	4.6	0.022	2.4	0.047	2.4	0.024
CO	56	0.0035	56	0.0013	33	0.0031	33	0.0015
Particulates	30	0.17	30	0.061	0.25	0.0021	0.25	0.0010
SO_2 (Uncontrolled)	448	1.79	448	0.66	0.25	0.0015	0.25	0.0007
SO_3	13.8	7.43	13.8	2.76	ND	ND	ND	ND
Particulate Sulfate	3.3	1.48	3.3	0.55	ND	ND	ND	ND
Trace Elements								
Beryllium	0.0024	0.52	0.0024	0.19	BD	NA	BD	NA
Chlorine	3.1	0.201	3.1	0.072	2.9	0.29	2.9	0.14
Copper	0.35	0.77	0.35	0.29	0.021	0.069	0.021	0.034
Lead	0.034	0.098	0.034	0.036	BD	NA	BD	NA
Magnesium	2.4	0.18	2.4	0.065	BD	NA	BD	NA
Mercury	0.0015	0.013	0.0015	0.005	0.0049	0.064	0.0049	0.031
Nickel	0.43	1.90	0.43	0.71	0.042	0.28	0.042	0.14
Phosphorus	0.13	0.57	0.13	0.21	0.070	0.46	0.070	0.23
Selenium	0.025	0.056	0.025	0.021	BD	NA	BD	NA
Vanadium	3.7	3.22	3.7	1.19	BD	NA	BD	NA
POM								
Benzopyrenes/perylenes	6.25×10^{-7}	0.014	6.25×10^{-7}	0.005	BD	NA	BD	NA
Total POM	0.0047	NA	0.0047	NA	BD	NA	BD	NA

ND - No data.
BD - Below detection limit. Detection limit for POM was typically 0.3 μg/m³ or approximately 0.0001 ng/J. However, lower detection limits were obtained for less complex samples with fewer interferences or closely eluting GC peaks.
NA - Not applicable.

Sulfates—

- Flue gas emissions of SO_3 (in the form of sulfuric acid vapor and aerosol) and particulate sulfate from bituminous coal-fired, lignite-fired, and residual oil-fired utility boilers require further attention. Source severity factors for known SO_3 emissions range from 0.26 to 7.4. Source severity factors for controlled emissions of particulate sulfate range from 0.15 to 0.93.

Trace Elements—

- Of the trace elements present in bituminous coal, flue gas emissions of aluminum, beryllium, chlorine, cobalt, chromium, iron, nickel, phosphorus, lead, and silicon from most coal-fired boilers are of environmental significance.
- Of the trace elements present in residual oil, flue gas emissions of beryllium, chlorine, copper, magnesium, nickel, phosphorus, lead, selenium, and vanadium from residual oil-fired boilers, with mean source severity factors greater than 0.05, warrant special concern.
- Measurements of flue gas emissions from gas-fired utility boilers indicated that the average emissions of chlorine, copper, mercury, nickel, and phosphorus were associated with source severity factors greater than 0.05. This is a surprising result requiring further characterization studies for confirmation.

Organics and POM—

- Analysis of organic emissions from utility sites indicated that the principal organic constituents in flue gas are glycols, ethers, ketones, and saturated and aliphatic hydrocarbons. The most prevalent species appear to be the glycols and ethers which have MATE values in the range of 10 to 1100 mg/m^3. Mean source severities calculated using these MATE values indicated that emissions of specific organics (excluding POM) are probably not of concern with respect to human health.
- POM compounds emitted at the highest concentrations in flue gas streams from bituminous coal-fired sources include naphthalene, phenanthrene, and pyrene. Dibenz(a,h)anthracene and possibly benzo(a)pyrene, both active carcinogens, were detected at a limited number of sites at levels of environmental concern.
- The only POM compounds identified in flue gas emissions from lignite-fired sources were biphenyl and trimethyl propenyl naphthalene. Carcinogenic POM compounds were not detected. The POM data base for lignite-fired utility boilers is considered to be adequate.
- For residual oil-fired sources, POM compounds emitted at the highest concentrations in flue gas streams are naphthalene and biphenyl. Carcinogenic POM compounds were not detected. The POM data base for residual oil-fired utility boilers is adequate.
- No POM was detected in flue gas streams from gas-fired utility boiler sites.

Characteristics of Air Emissions From Cooling Towers

- Air emissions of chlorine, magnesium, and phosphorus from mechanical draft cooling towers with high drift rates are comparable to flue gas emissions of these elements from residual oil-fired utility boilers and of environmental significance.
- Sulfate emissions from mechanical draft cooling towers employing sulfuric acid as an additive, and with design drift losses in the 0.1 to 0.2 percent range, are of the same magnitude as sulfate emissions from coal-fired and oil-fired utility boilers.

Characteristics of Wastewater Discharges

- The results of sampling and analysis for cooling tower blowdown, boiler blowdown, and ash pond overflow, combined with existing data, are summarized in Table 4. Also listed in this table are discharge severities, defined as the ratio of discharge concentration to the health based water Minimum Acute Toxicity Effluent (MATE) value.
- Characterization data for water treatment wastewater, FGD wet scrubber wastewater, coal pile runoff, and chemical cleaning wastes, based on previous studies are summarized in Tables 5 and 6.
- The major sources of wastewater discharges from external combustion sources for electricity generation are: once-through cooling water, blowdown from recirculating cooling systems, wastes from water treatment processes, chemical cleaning wastes, and coal pile runoff. Discharges from once-through cooling systems amount to 7,780,000 l/sec and account for approximately 99.8 percent of the total wastewater from conventional utility power plants. Of the remaining sources, blowdown from recirculating cooling systems is the largest contributor to wastewater discharge.
- From an environmental standpoint, the pollutants of most concern in wastewater effluents from conventional utility power plants are iron, magnesium, manganese, nickel, and phosphorus.
- The average organic levels in the ash pond effluents sampled were less than 0.1 mg/l. Average organic levels in the cooling tower blowdown and boiler blowdown sampled were 1.5 mg/l and 6.0 mg/l, respectively. POM compounds were not found above the detection limit of 2 μg/l.
- Based on discharge severities, the once-through cooling water and ash pond overflow streams appear to be of lesser environmental significance than the other wastewater streams from conventional fossil-fueled steam electric plants. Total pollutant loading from wastewater streams will, however, depend on individual discharge flow rates.

Characteristics of Solid Wastes

- The results from analysis of fly ash and bottom ash samples from bituminous coal-fired and lignite-fired utility boilers, supplemented by data from previous studies, are summarized in Table 7.
- Solid waste streams generated by conventional utility power plants consist primarily of coal ash and sludge from FGD systems. In 1978, total ash production was 63.6 Tg and total FGD sludge production was 2.1 Tg (on ash-free basis).
- Concentrations of 11 to 16 trace elements in bituminous coal ash and lignite ash exceed their health based solid MATE values. The pollutants of most concern are aluminum, arsenic, calcium, chromium, iron, manganese, nickel, potassium, and silicon.

Table 4. *Summary of Assessment Results for Cooling Tower Blowdown, Boiler Blowdown, and Ash Pond Overflow*

Constituent	Cooling Tower Blowdown		Boiler Blowdown		Fly Ash Pond Overflow		Bottom Ash Pond Overflow		Combined Ash Pond Overflow	
	Effluent Concentration	Discharge Severity	Effluent Concentration	Discharge Severity	Effluent Concentration	Discharge Severity	Effluent Concentration	Discharge Severity	Effluent Concentration	Discharge Severity
Gross Parameters										
pH	7.3	NA	10.5	NA	5.8	NA	7.4	NA	9.2	NA
Conductivity, μmhos/cm	3,050	NA	150	NA	10,000	NA	6,000	NA	480	NA
Hardness, (as $CaCO_3$), mg/l	1,220	NA	340	NA	220	NA	205	NA	185	NA
Alkalinity (as $CaCO_3$), mg/l	56	NA	97	NA	30	NA	62	NA	81	NA
TSS, mg/l	26	NA	87	NA	49	NA	41	NA	33	NA
BOD, mg/l	18	NA	3.0	NA	ND	NA	ND	NA	ND	NA
COD, mg/l	94	NA	53	NA	ND	NA	ND	NA	ND	NA
Trace Elements, mg/l										
Arsenic	0.28	1.1	—	—	8.7	35	2.2	8.9	—	—
Calcium	1,700	0.89	—	—	—	—	—	—	—	—
Cadmium	0.094	1.9	—	—	—	—	—	—	—	—
Chromium	0.48	1.9	—	—	—	—	—	—	—	—
Iron	1.8	1.2	—	—	1.2	0.80	2.5	1.7	—	—
Magnesium	650	1.4	—	—	—	—	410	0.85	—	—
Manganese	0.30	1.2	—	—	0.25	1.0	0.19	0.76	—	—
Nickel	—	—	—	—	0.40	1.8	—	—	—	—
Phosphorus	9.9	6.6	8.0	5.3	—	—	—	—	—	—
Selenium	0.081	1.6	—	—	—	—	—	—	—	—
Silicon	—	—	—	—	—	—	—	—	—	—
Chloride, mg/l	—	—	—	—	—	—	—	—	—	—
Sulfate, mg/l	1,300	1.0	—	—	—	—	—	—	—	—
Phenols, mg/l	—	—	0.026	5.2	—	—	—	—	—	—
Organics, mg/l										
Total volatile (C_7-C_{16})	0.021	NA	1.3	NA	0	NA	0.007	NA	0	NA
Total nonvolatile (>C_{16})	1.41	NA	4.7	NA	0.056	NA	0.090	NA	0.070	NA

ND - No data because analysis for these parameters was not performed.
NA - Not applicable because there are no MATE values associated with these parameters to compute discharge severities.
Data for constituents with discharge severities less than 1.0 are indicated by "—".

- Organics in bituminous coal ash and lignite ash are mostly present as the C16 fraction. POM concentrations in fly ash and bottom ash are not at levels of environmental concern. The only POM compounds detected were naphthalene, alkyl naphthalenes, and other compounds with high MATE values.

Recommendations

Because of inadequacies in the data base that characterizes emissions from external combustions for electricity generation, it is recommended that additional studies be conducted to provide the identified key data needs. These key data needs are discussed as follows.

Flue Gas Emissions—

- The combination of emissions data from this measurement program and the existing data base provides adequate characterization of flue gas emissions of criteria pollutants from most external combustion sources for electricity generation. The notable exception is the lack of emissions data for pulverized dry bottom boilers firing Texas lignite. This is a serious data deficiency because approximately 16,000 MW of added generating capacity are planned for this source category in the 1978-1985 period.
- Size distribution data for flue gas, emissions of particulates are inadequate for bituminous coal-fired, lignite-fired , and residual oil-fire utility boilers.
- For bituminous coal-fired and resi dual oil-fired utility boilers, th data base for SO_3 emissions i adequate. However, SO_3 emission data for lignite-fired sources ar presently unavailable.
- The data base for uncontrolle particulate sulfate emissions fro residual oil-fired sources is ade quate. The data base for controlle particulate sulfate emissions fro bituminous coal-fired and lignit fired sources, however, is inad quate.
- For bituminous coal-fired boile equipped with electrostatic precip tators, the data base characterizin

Table 5. *Summary of Assessment Results for Water Treatment Wastewater, Wet Scrubber Wastewater, and Coal Pile Runoff*

Constituent	Water Treatment Wastewater: Ion Exchange Effluent Concentration	Ion Exchange Discharge Severity	Clarification Effluent Concentrataion	Clarification Discharge Severity	Wet Scrubber Wastewater*: Effluent Concentration	Wet Scrubber Wastewater*: Discharge Severity	Coal Pile Runoff: Effluent Concentration	Coal Pile Runoff: Discharge Severity
Gross Parameters								
pH	ND	NA	ND	NA	7.5	NA	2.7	NA
Hardness (as $CaCO_3$), mg/l	1,000	NA	3,300	NA	ND	NA	ND	NA
Alkalinity (as $CaCO_3$), mg/l	560	NA	340	NA	108	NA	ND	NA
TSS, mg/l	32	NA	25,200	NA	ND	NA	330	NA
BOD, mg/l	36	NA	20	NA	ND	NA	ND	NA
COD, mg/l	48	NA	160	NA	185	NA	ND	NA
Trace Elements, mg/l								
Aluminum	—	—	160	1.1	—	—	150	1.0
Beryllium	—	—	—	—	0.04	1.3	0.03	1.0
Chromium	0.27	1.0	0.61	2.4	—	—	—	—
Copper	—	—	—	—	—	—	—	—
Iron	4.2	2.8	350	233	—	—	660	440
Lead	—	—	—	—	—	—	—	—
Magnesium	—	—	—	—	580	1.2	—	—
Manganese	—	—	—	—	0.85	3.4	33	131
Mercury	—	—	—	—	0.044	4.4	—	—
Nickel	—	—	0.32	1.5	0.50	2.3	1.5	6.6
Phosphorus	—	—	—	—	—	—	—	—
Selenium	—	—	—	—	0.59	12	—	—
Sodium	3,200	4.0	—	—	1,100	1.4	—	—
Zinc	—	—	—	—	—	—	—	—
Chloride, mg/l	1,800	1.5	—	—	2,500	2.1	—	—
Sulfate, mg/l	—	—	—	—	4,700	3.6	—	—
Ammonia, mg/l	—	—	—	—	—	—	—	—
Hydrazine, mg/l	—	—	—	—	—	—	—	—
Phenols, mg/l	—	—	—	—	—	—	—	—

*Sludge liquor from lime/limestone FGD scrubber
ND - No data.
NA - Not applicable because there are no MATE values associated with these parameters to compute discharge severities.
Data for constituents with discharge severities less than 1.0 are indicated by "—".

flue gas emissions is adequate for most trace elements. Similar data bases characterizing flue gas emissions of trace elements from sources equipped with wet scrubbers and mechanical precipitators, however, are inadequate.

- Existing data for flue gas emissions of trace elements from lignite-fired utility boilers are generally not available. Analysis of the data acquired in this program indicated the need for additional characterization studies. The most serious data deficiency is the characterization of flue gas emissions of trace elements from pulverized dry bottom boilers firing Texas lignite, a source category with increasing importance in power generation.
- The data base characterizing flue gas emissions of trace elements from residual oil-fired utility boilers appears to be adequate except for beryllium, calcium, chlorine, copper, fluorine, magnesium, lead, selenium, and vanadium. The emissions data base for these trace elements can be improved by analysis of additional residual oil samples.
- The Level I SSMS technique has served its purpose in providing valuable trace element survey and screening data. To more accurately determine the emission levels of these potentially hazardous trace elements, it is important that future source tests and analyses be conducted using Level II techniques on a selected number of trace elements, with the primary objective that meaningful enrichment factors can be calculated.
- Although current data indicated that emissions of specific organics (excluding POM) are probably not of concern with respect to human health, more detailed Level II organic analysis would be required to conclusively determine the significance of organic emissions.
- The data base characterizing flue gas emissions of POM from bituminous coal-fired sources is adequate except for dibenz(a,h)anthracene and benzo(a)pyrene. Emissions of these specific POM compounds will require further characterization.

Table 6. *Summary of Assessment Results for Chemical Cleaning Wastes*

Constituent	Chemical Cleaning Wastes: Acid Phase Composite		Alkaline Phase Composite		Neutralization Drain	
	Effluent Concentration	Discharge Severity	Effluent Concentration	Discharge Severity	Effluent Concentration	Discharge Severity
Gross Parameters						
pH	1.1	NA	ND	NA	11.4	NA
Hardness (as $CaCO_3$), mg/l	ND	NA	ND	NA	ND	NA
Alkalinity (as $CaCO_3$), mg/l	ND	NA	ND	NA	ND	NA
TSS, mg/l	45	NA	67	NA	47	NA
BOD, mg/l	ND	NA	ND	NA	ND	NA
COD, mg/l	2,870	NA	90	NA	70	NA
Trace Elements, mg/l						
Aluminum	—	—	—	—	—	—
Beryllium	—	—	—	—	—	—
Chromium	2.9	12	—	—	—	—
Copper	15	3.0	530	106	5.1	1.0
Iron	2,880	1,920	2.4	1.6	7.3	4.8
Lead	2.1	8.2	—	—	—	—
Magnesium	—	—	—	—	—	—
Manganese	19	77	-	—	—	—
Mercury	—	—	—	—	—	—
Nickel	178	809	1.6	7.1	—	—
Phosphorus	35	23	143	95	755	503
Selenium	—	—	—	—	—	—
Sodium	—	—	—	—	0.060	1.3
Zinc	48	1.9	—	—	—	—
Chloride, mg/l	—	—	—	—	—	—
Sulfate, mg/l	—	—	—	—	—	—
Ammonia, mg/l	—	—	2,740	10	—	—
Hydrazine, mg/l	—	—	—	—	0.013	5.7
Phenols, mg/l	0.044	8.8	—	—	—	—

ND - No data.
NA - Not applicable because there are no MATE values associated with these parameters to compute discharge severities.
Data for constituents with discharge severities less than 1.0 are indicated by "—"

Wastewater Discharges—

- The data bases characterizing cooling tower blowdown, ash pond overflow, chemical cleaning wastes, wet scrubber wastewater, and coal pile runoff are inadequate. The present study has been instrumental in applying Level I techniques to identification of wastewater constituents which pose potential environmental problems. Since potential problems were detected by Level I techniques, further studies using Level II techniques will be required to adequately characterize wastewater effluents from utility boilers.

Solid Wastes—

- Data on FGD scrubber sludge are limited. Needed data will be provided by extensive scrubber sludge characterization studies currently in progress under the direction of EPA and the Electric Power Research Institute (EPRI).

Table 7. Summary of Assessment Results for Fly Ash and Bottom Ash from Bituminous Coal-Fired and Lignite-Fired Boilers

Pollutant	Bituminous Fly Ash		Bituminous Bottom Ash		Lignite Fly Ash		Lignite Bottom Ash	
	Concentration (ppm)	Discharge Severity	Concentration (ppm)	Discharge Severity	Concentration (ppm)	Discharge Severity	Concentration (ppm)	Discharge Severity
Trace Elements								
Aluminum	4,300-100,000	0.27-6.3	3,700-90,000	0.23-5.6	3,500-35,000	0.22-2.2	8,100-27,000	0.51-1.7
Arsenic	3-240	0.06-4.8	1-18	0.02-0.36	79-830	1.6-17	22-400	0.44-8.0
Barium	280-640	0.28-0.64	220-450	0.22-0.45	1,200-15,000	1.2-15	2,100-20,000	2.1-20
Boron	25-700	0.003-0.075	5.5-300	0.0006-0.032	320-13,000	0.034-1.4	490-6,300	0.053-0.68
Calcium	1,100-121,000	0.023-2.5	3,100-93,000	0.065-1.9	27,000-130,000	0.56-2.7	63,000-130,000	1.3-2.7
Chromium	19-300	0.38-6.0	15-220	0.30-4.4	8.1-64	0.16-1.3	5.1-22	0.10-0.44
Cobalt	7-57	0.047-0.38	4-31	0.027-0.21	7.1-1,200	0.047-8.0	6-11	0.04-0.073
Iron	32,000-143,000	110-480	47,000-213,000	160-710	1,000-11,000	3.3-37	27,000-71,000	90-240
Lead	7-110	0.14-2.2	6-120	0.12-2.4	9.3-160	0.19-3.2	4.3-150	0.086-3.0
Lithium	46-86	0.66-1.2	3-60	0.043-0.86	1.3-62	0.019-0.89	3.8-79	0.054-1.1
Magnesium	820-13,400	0.046-0.74	1,300-12,400	0.072-0.69	17,000-32,000	0.94-1.8	4,600-35,000	0.26-1.9
Manganese	100-300	2.0-6.0	37-860	0.74-17	200-1,300	4.0-26	310-1,000	6.2-20
Mercury	0.01-28	0.0005-1.4	0.1-0.5	0.005-0.025	0.086-2.0	0.0043-0.1	<0.017-0.094	<0.001-0.0047
Nickel	10-250	0.22-5.6	0.3-100	0.007-2.2	21-1,600	0.47-36	44-140	0.93-3.1
Phosphorus	82-5,100	0.027-1.7	120-3,800	0.04-1.3	120-4,600	0.04-1.5	110-5,200	0.037-1.7
Potassium	2,900-20,000	0.69-4.8	1,000-15,800	0.24-3.8	1,200-30,000	0.29-7.1	660-15,000	0.16-3.6
Selenium	4-32	0.4-3.2	<1-5.6	<0.1-0.56	<0.21-19	<0.21-1.9	1.3-5.5	0.13-0.55
Silicon	17,000-276,000	0.57-9.2	7,500-276,000	0.25-9.2	34,000-53,000	1.1-1.8	31,000-50,000	1.0-1.7
Organics								
Total Volatile (C_1-C_{16})	<14-87	NA	<14-87	NA	0.5-15	NA	0.9-11	NA
Total nonvolatile (>C_{16})	0-420	NA	0-900	NA	43-300	NA	150-300	NA

NA - Not applicable. Discharge severities for C_1-C_{16} and >C_{16} organics were not computed because there is no representative MATE value for either group.

C. C. Shih, R. A. Orsini, D. G. Ackerman, R. Moreno, E. L. Moon, L. L. Scinto, and C. Yu are with TRW Environmental Engineering Division, Redondo Beach, CA 90278.
Michael C. Osborne is the EPA Project Officer (see below).

The complete report, entitled "Emissions Assessment of Conventional Stationary Combustion Systems: Volume III. External Combustion Sources for Electricity Generation," (Order No. PB 81-145 195; Cost: $33.50, subject to change) will be available only from:
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Telephone: 703-487-4650

The EPA Project Officer can be contacted at:
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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