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ENVIRONMENTAL ASSESSMENT OF A FIRETUBE BOILER FIRING COAL/OIL/WATER MIXTURES

Volume I. Technical Results

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Prepared by

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ENVIRONMENTAL ASSESSMENT OF A FIRETUBE BOILER FIRING COAL/OIL/WATER MIXTURES

Volume I
Technical Results

by

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SECTION 1

INTRODUCTION

This report describes and presents results for a set of environmental assessment tests performed for the Environmental Protection Agency's Industrial Environmental Research Laboratory/Research Triangle Park (EPA-IERL/RTP) under the Combustion Modification Environmental Assessment (CMEA) program, EPA Contract No. 68-02-3188. The CMEA started in 1976 with a 3-year study, the NO_x Control Technology Environmental Assessment (NO_x EA, EPA Contract No. 68-02-2160), having the following four objectives:

- Identify potential multimedia environmental effects of stationary combustion sources and combustion modification technology
- Develop and document control application guidelines to minimize these effects
- Identify stationary source and combustion modification R&D priorities
- Disseminate program results to intended users

During the first year of the NO_x EA, data for the environmental assessment were compiled and methodologies were developed. Furthermore, priorities for the schedule and level of effort to be devoted to evaluating the various source/fuel/control combinations were identified. This effort revealed major data gaps, particularly for noncriteria pollutants (organic emissions and trace elements) for virtually all combinations of stationary

combustion sources and combustion modification techniques. Consequently, a series of seven environmental field test programs was undertaken to fill these data gaps. The results of these tests are documented in seven individual reports (References 1-1 through 1-7) and in the NO_x EA final report summarizing the entire 3-year effort (Reference 1-8).

The current CMEA program has, as major objectives, the continuation of multimedia environmental field tests initiated in the original NO_x EA program. These new tests, using standardized Level 1 sampling and analytical procedures (Reference 1-9) are aimed at filling the remaining data gaps and addressing the following priority needs:

- Advanced NO_x controls
- Alternate fuels
- Secondary sources
- EPA program data needs
  - -. Residential oil combustion
  - -- Wood firing in residential, commercial, and industrial sources
  - -- High interest emissions determination (e.g., listed and candidate hazardous air pollutant species)
- Nonsteady-state operation

In recent years coal-oil mixtures have received significant attention as potential alternate fuels for utility and industrial boilers as a means of reducing the consumption of fuel oil in these units, thus reducing the nation's dependence on expensive and unreliable sources of imported oil. Although generally still at the R&D stage, coal-oil mixtures (COM) and coal-oil-water mixtures (COW) with up to 50 percent coal on a weight basis have been investigated in a number of industrial and utility sources. More

recently coal-water-slurry (CWS) mixtures with up to 70 percent coal by weight have been tested. Pending optimization of fuel mixing, storage, handling, and combustion procedures, these mixtures are considered feasible alternatives to oil as a boiler fuel.

An industrial firetube boiler burning a mixture of coal, oil, and water was selected for multimedia environmental testing under the CMEA program. The objectives of the tests were to quantify emissions from the boiler burning COW only, and with soda ash (sodium carbonate) added to the COW for sulfur oxides emission control. The data presented in this report quantify stack emissions and identify pollutants of possible concern using results from standardized sampling and analytical procedures.

In addition to this program, a COM-fired industrial boiler, another COW-fired industrial boiler, and two CWS-fired industrial boilers were tested to evaluate further the potential environmental impact of these fuels. Results of these tests are documented in separate reports (References 1-10 through 1-13). The interested reader is advised to review results from all these test programs to obtain a more complete evaluation of the environmental aspects of combustion of COM, COW, and CWS fuel mixtures.

Table 1-1 lists all the sources tested in the CMEA effort, outlining the source characteristics, fuel used, combustion modifications implemented, and the level of sampling and analysis performed in each case. Results of these test programs are discussed in separate reports.

TABLE 1-1. COMPLETED TESTS DURING THE CURRENT PROGRAM

Source	Description	Test points unit operation	Sampling protocol	Test collaborator
Spark-ignited, natural-gas-fired reciprocating internal combustion engine	Large bore, 6-cylinder, opposed piston, 186-kW (250 Bhp)/cyl, 900-rpm Model 38TDS8-1/8	-- Baseline (pre-NSPS) -- Increased air-fuel ratio aimed at meeting proposed NSPS of 700 ppm corrected to 15 percent O_2 and standard atmospheric conditions	Engine exhaust: -- SASS -- Method 5 -- Gas sample (C_1-C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Lube oil	Fairbanks Morse Division of Colt Industries
Compression ignition, diesel-fired, reciprocating internal combustion engine	Large bore, 6-cylinder opposed piston, 261-kW (350 Bhp)/cyl, 900-rpm Model 38TDD8-1/8	-- Baseline (pre-NSPS) -- Fuel injection retard aimed at meeting proposed NSPS of 600 ppm corrected to 15 percent O_2 and standard atmospheric conditions	Engine exhaust: -- SASS -- Method 8 -- Method 5 -- Gas sample (C_1-C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Lube oil	Fairbanks Morse Division of Colt Industries
Low-NO_x, residential, condensing-heating system furnished by Karlsons Blueburner Systems Ltd. of Canada	Residential hot water heater equipped with M.A.N. low-NO_x burner, 0.55 ml/s (0.5 gal/hr) firing capacity, condensing flue gas	Low-NO_x burner design by M.A.N.	Furnace exhaust: -- SASS -- Method 8 -- Method 5 -- Gas sample (C_1-C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Waste water	New test
Rocketdyne/EPA low-NO_x residential forced warm air furnace	Residential warm air furnace with modified high-pressure burner and firebox, 0.83 ml/s (0.75 gal/hr) firing capacity	Low-NO_x burner design and integrated furnace system	Furnace exhaust: -- SASS -- Method 8 -- Controlled condensation -- Method 5 -- Gas sample (C_1-C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel	New test

TABLE 1-1. CONTINUED

Source	Description	Test points unit operation	Sampling protocol	Test collaborator
Pulverized coal-fired utility boiler, Conesville station	400-MW tangentially fired; new NSPS design aimed at meeting 301 ng/J NO_x limit	ESP inlet and outlet, one test	ESP inlet and outlet -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1-C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2 Coal Bottom ash ESP ash	Exxon Research and Engineering (ER&E) conducting corrosion tests
Nova Scotia Technical College industrial boiler	1.14 kg/s steam (9,000 lb/hr) firetube fired with a mixture of coal-oil-water (COW)	-- Baseline (COW) -- Controlled SO_2 emissions with limestone injection	Boiler outlet -- SASS -- Method 5 -- Method 8 -- Controlled condensation -- Gas sample (C_1-C_6 HC) -- Continuous O_2, CO_2, CO, NO_x Fuel	Envirocon performed particulate and sulfur emission tests
Adelphi University industrial boiler	1.89 kg/s steam (15,000 lb/hr) hot water firetube fired with a mixture of coal-oil-water (COW)	-- Baseline (COW) -- Controlled SO_2 emissions with Na_2CO_3 injection	Boiler outlet -- SASS -- Method 5 -- Method 8 -- Controlled condensation -- Gas Sample (C_1-C_6 HC) -- Continuous O_2, CO_2, NO_x, SO_2, CO Fuel	Adelphi University
Pittsburgh Energy Technology Center (PETC) industrial boiler	3.03 kg/s steam (24,000 lb/hr) watertube fired with a mixture of coal-oil (COM)	-- Baseline test only with COM	Boiler outlet -- SASS -- Method 5 -- Controlled condensation -- Continuous O_2, CO_2, NO_x, TUHC, CO Fuel	PETC and General Electric (GE)

TABLE 1-1. CONTINUED

Source	Description	Test points unit operation	Sampling protocol	Test collaborator
TOSCO Refinery vertical crude oil heater	2.54 Ml/day (16,000 bbl/day) natural draft process heater burning oil/refinery gas	-- Baseline -- Staged combustion using air injection lances	Heater outlet -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1-C_6 HC) -- Continuous O_2, NO_x, CO, CO_2, HC -- N_2O grab sample Fuel oil Refinery gas	KVB coordinating the staged combustion operation and continuous emission monitoring
Mohawk-Getty Oil industrial boiler	8.21 kg/s steam (65,000 lb/hr) watertube burning mixture of refinery gas and residual oil	-- Baseline -- Ammonia injection using the noncatalytic Thermal DeNO$_x$ Process	Economizer outlet -- SASS -- Method 5, 17 -- Controlled condensation -- Gas Sample (C_1-C_6 HC) -- Ammonia emissions -- N_2O grab sample -- Continuous O_2, NO_x, CO, CO_2 Fuels (refinery gas and residual oil)	New test
Industrial boiler	2.52 kg/s steam (20,000 lb/hr) watertube burning wood waste	-- Baseline (dry wood) -- Wet (green) wood	Boiler outlet -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1-C_6 HC) -- Continuous O_2, NO_x, CO Fuel Flyash	North Carolina Department of Natural Resources, EPA IERL-RTP
Industrial boiler	3.16 kg/s steam (29,000 lb/hr) firetube with refractory firebox burning wood waste	-- Baseline (dry wood)	Outlet of cyclone particulate collector -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1-C_6 HC) -- Continuous O_2, NO_x, CO Fuel Bottom ash	North Carolina Department of Natural Resources, EPA IERL-RTP

TABLE 1-1. CONTINUED

Source	Description	Test points unit operation	Sampling protocol	Test callaborator
Enhanced oil recovery steam generator	15 MW (50 million Btu/hr) steam generator burning crude oil equipped with MHI low-NO_x burner	-- Performance mapping -- Low NO_x operation	Steamer outlet: -- SASS -- Method 5 -- Method 8 -- Gas sample (C_1 - C_6 HC) -- Continuous 02, NO_x, CO, CO_2 -- N_2O grab sample Fuel	Getty Oil Company, CE-Natco
Pittsburgh Energy Technology Center (PETC) industrial boiler	3.03 kg/s steam (24,000 lb/hr) watertube fired with a mixture of coal-water (CWM)	-- Baseline test only with CWM	Boiler outlet: -- SASS -- Method 5 -- Method 8 -- Gas sample (C_1 - C_6 HC) -- Continuous O_2, NO_x, CO, CO_2, TUHC -- N_2O grab sample Fuel Bottom ash Collector hopper ash	PETC and General Electric
Internal combustion engine -- nonselective NO_x catalyst	610 kW (818 hp) Waukesha engine equipped with DuPont NSER catalyst	-- Baseline -- 15-day emissions monitoring	Catalyst inlet and outlet -- SASS -- NH_3 -- HCN -- Grab sample N_2O -- Continuous O_2, CO_2, NO_x TUHC -- fuel	Southern California Gas Company
Industrial boiler	180 kg/hr steam (400 lb/hr) stoker fired with a mixture of coal and waste plastic beverage containers	-- Baseline (coal) -- Coal and plastic	Boiler outlet -- SASS -- VOST -- Method 5/8 -- HCl -- Continuous O_2, NO_x, CO, CO_2, TUHC -- N_2O grab sample Fuel Flyash Bottom ash Cyclone ash	Vermont Agency of Environmental Conservation

TABLE 1-1. CONTINUED

Source	Description	Test points unit operation	Sampling protocol	Test collaborator
Industrial boiler	7.6 kg/s steam (60,000 lb/hr) watertube retrofit for coal-water-slurry (CWS) firing	-- Baseline test with CWS -- 30-day emissions monitoring	Boiler outlet -- SASS -- VOST -- Method 5/8 -- Grab sample (C_1-C_6 HC) -- Grab sample N_2O -- Continuous NO_x, CO, CO_2, O_2, TUHC, SO_2 Fuel	EPRI, E. I. DuPont
Enhanced oil recovery steam generator	15 MW (50 million Btu/hr) steam generator burning crude oil, equipped with the EPA/EER low NO_x burner	-- Low NO_x (with burner) -- 30-day emission monitoring	Steamer outlet -- SASS -- VOST -- Method 5/8 -- Controlled condensation -- Anderson impactor -- Grab sample (C_1 - C_6 HC) -- N_2O grab sample -- Continuous NO_x, CO, CO_2, O_2, SO_2 Fuel	Chevron U.S.A., EERC

REFERENCES FOR SECTION 1

1-1. Larkin, R. and E. B. Higginbotham, "Combustion Modification Controls for Stationary Gas Turbines: Volume II. Utility Unit Field Test," EPA-600/7-81-122b, NTIS PB82-226473, July 1981.

1-2. Higginbotham, E. B., "Combustion Modification Controls for Residential and Commercial Heating Systems: Volume II. Oil-fired Residential Furnace Field Test," EPA-600/7-81-123b, NTIS PB82-231175, July 1981.

1-3. Higginbotham, E. B. and P. M. Goldberg, "Combustion Modification NO_x Controls for Utility Boilers: Volume I. Tangential Coal-fired Unit Field Test," EPA-600/7-81-124a, NTIS PB82-227265, July 1981.

1-4. Sawyer, J. W. and E. B. Higginbotham, "Combustion Modification NO_x Controls for Utility Boilers: Volume II. Pulverized-coal Wall-fired Unit Field Test," EPA-600/7-81-124b, NTIS PB82-227273, July 1981.

1-5. Sawyer, J. W. and E. B. Higginbotham, "Combustion Modification NO_x Controls for Utility Boilers: Volume III. Residual-oil Wall-fired Unit Field Test," EPA-600/7-81-124c, NTIS PB82-227281, July 1981.

1-6. Goldberg, P. M. and E. B. Higginbotham, "Industrial Boiler Combustion Modification NO_x Controls: Volume II. Stoker Coal-fired Boiler Field Test -- Site A," EPA-600/7-81-126b, NTIS PB82-231085, July 1981.

1-7. Lips, H. I. and E. B. Higginbotham, "Industrial Boiler Combustion Modification NO_x Control: Volume III. Stoker Coal-fired Boiler Field Test -- Site B," EPA-600/7-81-126c, NTIS PB82-231095, July 1981.

1-8. Waterland, L. R., et al., "Environmental Assessment of Stationary Source NO_x Control Technologies -- Final Report," EPA-600/7-82-034, NTIS PB82-249350, May 1982.

1-9. Lentzen, D. E., et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition)," EPA-600/7-78-201, NTIS PB293795, October 1978.

1-10. DeRosier, R., "Environmenal Assessment of a Watertube Boiler Firing Coal/Oil Mixture," Acurex Report TR-81-87/EE, March 1984.

1-11. Castaldini, C., "Environmental Assessment of an Industrial Boiler Burning Coal/Oil/Water Mixture," Acurex Report TR-81-86/EE, June 1984.

1-12. DeRosier, R., and L. R. Waterland, "Environmental Assessment of a Watertube Boiler Firing a Coal-Water-Slurry," Acurex Draft Report TR-84-156/EE, June 1984.

1-13. VanBuren, D., and L. R. Waterland, "Environmental Assessment of a Coal-Water-Slurry-Fired Industrial Boiler," Acurex Draft Report TR-84-155/EE, June 1984.

SECTION 2

SOURCE DESCRIPTION

The tests were performed on a modified Cleaver Brooks CB400-350 package boiler located at Adelphi University in Garden City, Long Island, New York. This firetube unit utilizes a four-pass design, consisting of a combustion section and three convective sections, with the cross-sectional area decreasing for each pass. Table 2-1 summarizes the boiler design data.

Changes in the original boiler design include a new fuel feed system to handle the COW mixture, a modified nozzle, larger atomizing air blowers and soot blowers. The fuel-feed system mixes the fuel in-line, where it is fed to a 210 l (55-gallon) storage tank. From the tank, the fuel proceeds through a Moyno pump to a Micro Motion flowmeter and then into the burner fuel gun. Modifications to the nozzle included increasing the center hole diameter from 0.64 cm (1/4 in.) to 0.95 cm (3/8 in.) to assure proper flow of COW. The blower capacity for fuel atomization was increased with the addition of a larger blower supplied by Cleaver Brooks. Front soot blowers were also installed. These consist of stainless steel impingers aimed at each of the three tube passes. These blowers operate on 520 or 620 kPa (75 or 100 psi) compressed air and can complete a full cycle in 15, 30, or 60 minutes as desired.

The first test was run with a COW mixture for approximately 6 hours. There were no unusual difficulties associated with this test. The second

TABLE 2-1. BOILER DESIGN DATA

Design heat input, MW (10^6 Btu/hr)	4.1 (14)
Design pressure kPa (psig)	1,030 (150)
Final water temperature, °C (°F)	135 (275)
Water/steam output, kg/hr (lb/hr)	5,476 (12,075)
Boiler heating surface, m^2 (ft^2)	163 (1,750)
Year built	1979

test, using COW with soda ash (COW+SA) added to reduce SO_2 emissions, lasted only 3.5 hours before it had to be terminated because of excessive ash deposition in the boiler tube passes. After completion of the two tests, 127 kg (281 lb) of ash were removed from the boiler, which had been cleaned prior to testing. Based on the fuel composition, fuel flowrate, and particulate emission rates, 20 percent of this ash was estimated to be attributed to the COW test and 80 percent to the COW+SA test. Section 3 discusses the boiler operating conditions and fuel composition as well as the emission results.

SECTION 3

EMISSION RESULTS

The objective of this test program was to measure and compare exhaust emissions from the boiler while burning a coal-oil-water (COW) mixture and COW with soda ash (COW+SA) for sulfur oxides control. This section describes the test arrangement and presents emissions results. Section 3.1 summarizes boiler operating conditions. Sections 3.2 through 3.5 summarize emission results by pollutant grouping; criteria and other gas phase emissions are discussed in Section 3.2; trace elements in Section 3.3; organic species in Section 3.4; and radionuclides in Section 3.5

3.1 BOILER OPERATION AND TEST ARRANGEMENT

Table 3-1 summarizes the boiler operating data for both the COW and the COW+SA tests. The addition of soda ash (sodium carbonate) to the COW caused the boiler tubes to foul quickly. This is evident from the rapid increase in stack temperature for the COW+SA test relative to the COW test as shown in Figure 3-1. The much higher initial stack temperature during the COW+SA test is partially the result of the ash deposited in the furnace and tube passes during the COW tests. In fact, the stack temperature at the end of the COW test is nearly equal to that at the start of the COW+SA test. The observed fouling rates could preclude using sorbent injection at levels needed to obtain significant SO_x reduction. In addition to the ash deposition effect, the higher stack temperature during the COW+SA test was also in part caused

TABLE 3-1. BOILER OPERATING CONDITIONS

	COW	COW+SA
Fuel flow, kg/hr (lb/hr)	433.5 (955.9)	429.5 (947.1)
Boiler feedwater flow, l/s (gal/min)	18.5 (293)	18.8 (298)
Excess air, percent[a]	17	14
Temperatures[b], °C (°F)		
Fuel:	25 (77)	32 (90)
Water return:	82 (179)	80 (176)
Water supply:	124 (256)	119 (246)
Ambient air:	23 (74)	24 (75)
Stack:	146 (295)	181 (357)

[a]Based on stack O_2 measurement (percent, dry) and fuel analysis.
[b]Average over test run.

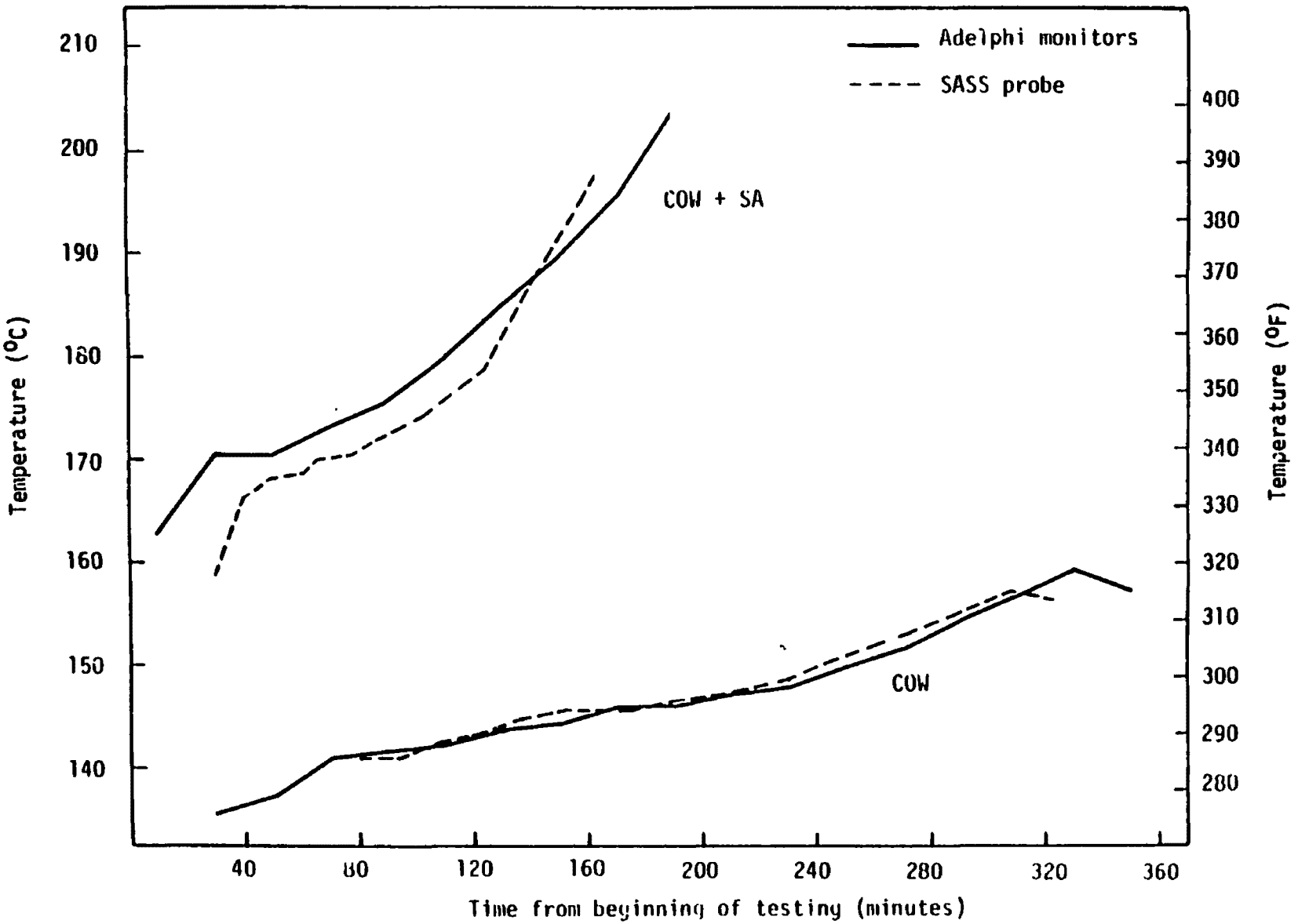


Figure 3-1. Stack gas temperature.

by the additional thermal mass contributed by the incombustible ash which lowered the flame temperature, reduced heat transfer in the furnace and, thus, contributed to higher exit gas temperatures.

Exhaust gas measurements were taken at the three locations shown in Figure 3-2. The exhaust gas temperature was measured within 1m (3 ft) of the boiler exit. One set of continuous monitors measured N_2, O_2, CO_2, H_2O and SO_2 in the first horizontal section of flue gas ducting. These readings were output roughly once per minute to a data acquisition computer as part of the normal Adelphi University monitoring system. In the second horizontal section of the duct, the following samples were taken:

- Source Assessment Sampling System (SASS)
- Controlled Condensation System (CCS) (sulfur oxides)
- Grab Sample for C_1-C_6 hydrocarbon measurement
- EPA Method 5 (particulate)
- Continuous Monitors for O_2, CO_2, CO, NO and NO_x

Sampling and analysis procedures conformed to a modified EPA Level 1 protocol (Reference 3-1).

As a consequence of the rapid boiler fouling with the soda ash addition, as noted above, the COW+SA test had to be terminated early (after 3.5 hours). Thus the volume of gas sampled by the SASS train for this test was only about 6 dscm, compared to about 24 dscm for the COW test.

3.2 CRITERIA POLLUTANT AND OTHER GAS PHASE SPECIES EMISSIONS

Table 3-2 summarizes gaseous and particulate emissions measured during the COW and COW+SA tests. Gas phase species emissions were measured with the continuous monitoring systems. All data in Table 3-2 were obtained by Acurex personnel with the exception of the SO_2 continuous-monitor measurements,

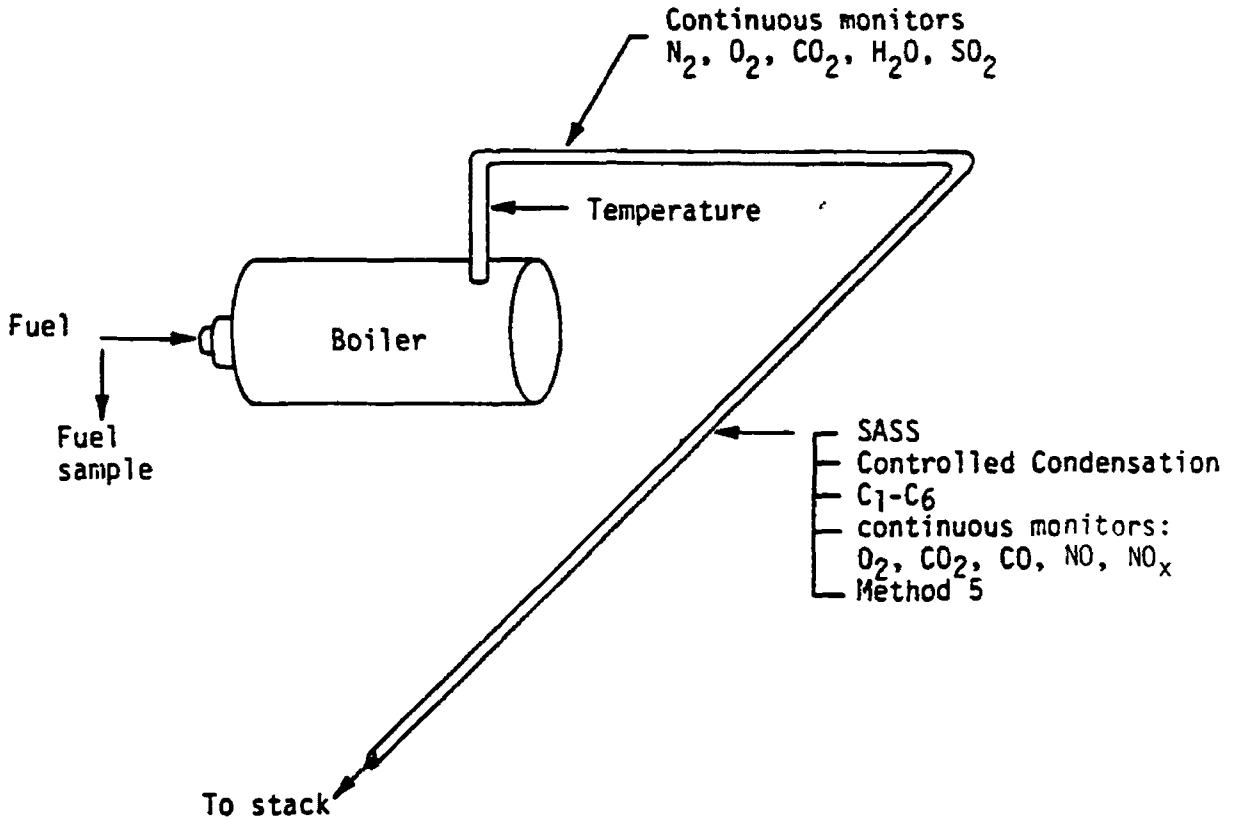


Figure 3-2. Sampling locations (sketch not to scale).

TABLE 3-2. FLUE GAS EMISSIONS

Pollutant	COW test			COW+SA test		
	Range	Average		Range	Average	
As measured:						
O_2, percent dry	1.8-3.7	3.3[a]		2.4-3.8	3.2	
CO_2, percent dry	11.5-15.0	13.6		12.5-14.1	13.0	
CO, ppm dry	12->1,000	25[a]		20->1,000	422	
NO, ppm dry	440-485	466		360-455	435	
NO_2, ppm dry	5	5		--[b]	--[b]	
NO_x, ppm dry	445-490	471		260-455	435	
SO_2, ppm						
Continuous monitor	1,285-1,732	1,402		2.3-138	48	
Controlled condensation	--[c]	1,071		--[c]	13.4	
SO_3, ppm						
Controlled condensation	--[c]	0.6		--[c]	0	
Water, percent		8.0			8.0	
Corrected	ppm[d]	ng/J	lb/10^6 Btu	ppm[d]	ng/J	lb/10^6 Btu
CO[e]	25[a]	11[a]	0.025[a]	426	195	0.45
NO[e]	472[a]	213[a]	0.50[a]	427	215	0.50
NO_2[e]	5[a]	3.5[a]	0.0081[a]			
NO_x (as NO_2)[e]	477[a]	332[a]	0.77[a]	427	330	0.77
SO_2						
Continuous monitor	1,426	1,309	3.23	48.5	50.7	0.12
Controlled condensation	1,089	1,061	2.47	13.6	14.1	0.033
SO_3						
Controlled condensation	0.6	0.74	0.0017	0	0	0
Particulate	mg/dscm			mg/dscm		
SASS	1,972	722	1.68	3,715	1,457	3.39
Method 5	--[f]	--[f]	--[f]	3,721	1,459	3.39

[a]Average over the first 3.5 hours of stable operation.
[b]Not recorded for this test.
[c]Extractive sample over test duration, range not applicable.
[d]Corrected to 3 percent O_2 dry.
[e]Average of corrected values.
[f]Sample not taken.

which were supplied by Adelphi University. Sulfur oxide emissions were also measured using the CCS train. Particulate emissions were measured by Adelphi University using EPA Method 5 and by Acurex using the SASS train. The SASS train was used primarily for collection of samples for analysis of trace elements and organic species. Thus, while not the particulate reference method, it does give a measure of particulate emissions. Equipment and sampling procedures used for emissions measurement are described in Appendix A.

Table 3-2 shows that CO emissions in both tests ranged from the low ppm (12-20) range to over 1,000 ppm. As shown in Figures 3-3 and 3-4, CO emissions increased markedly whenever the O_2 level dropped below a certain critical concentration. For the COW test, the critical flue gas O_2 was about 3 percent, with CO levels in excess of 1,000 ppm when the O_2 level dropped below 2.5 percent. In the COW+SA test, although the CO levels were higher, the critical O_2 concentration was also higher, around 3.2 percent. The addition of soda ash to the COW mixture greatly increased CO emissions. This may be explained by the lower flame temperature caused by the addition of large amounts of incombustible material which must also be heated. Thus, combustion efficiency is lowered and more CO remains unconverted to CO_2.

Besides the increase in average CO emissions, the soda ash addition produced a greater variation in CO emissions. In the COW test, CO emissions fluctuated within a 20 ppm range when the flue gas O_2 was above 3 percent. This fluctuation increased to ±40 ppm when the O_2 level dropped below the 3 percent level. With the addition of soda ash, CO emissions fluctuated within a 100 ppm range when flue gas O_2 was above 3.2 percent, increasing to ±400 ppm when the O_2 level dropped below 3.2 percent. In both cases, the

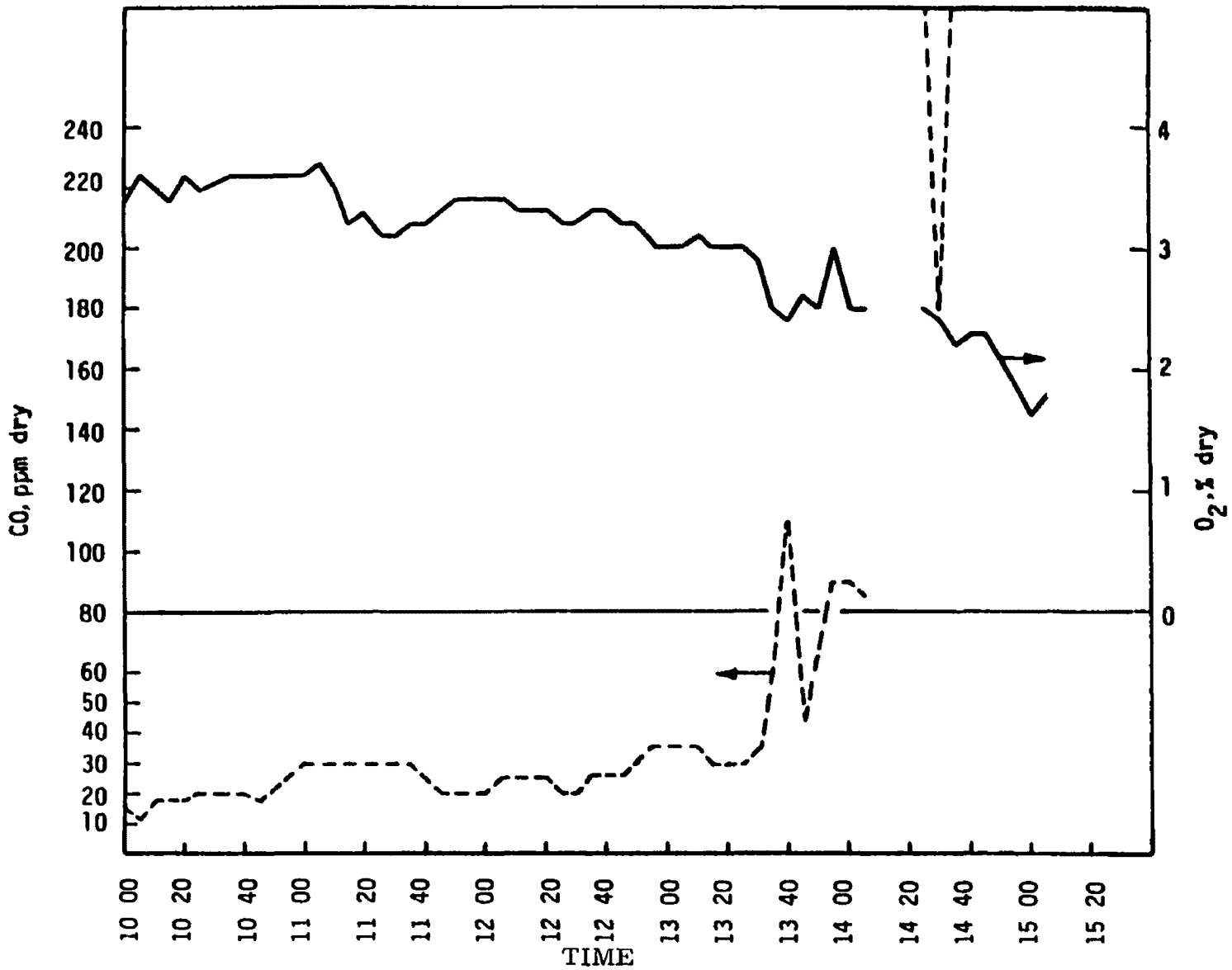


Figure 3-3. Flue gas CO and O_2: COW test.

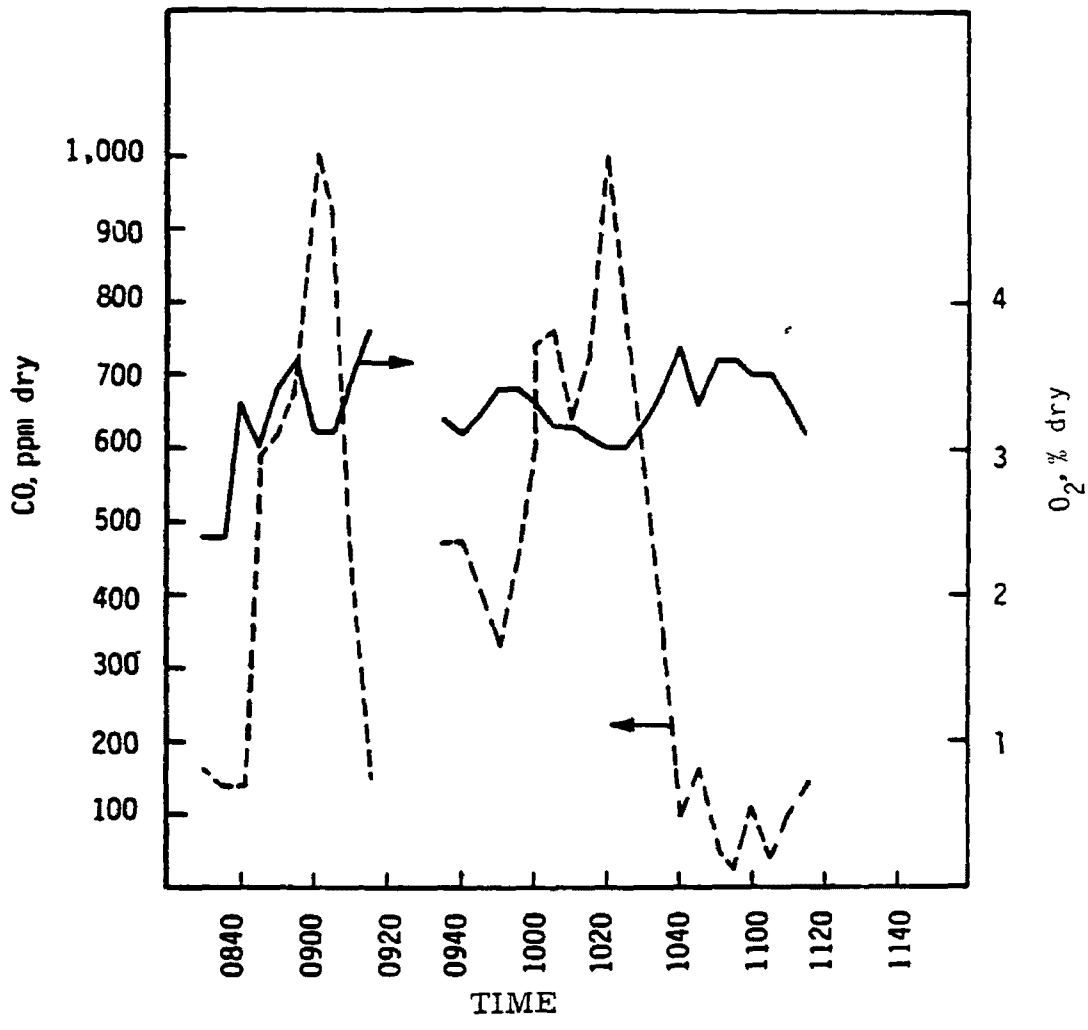


Figure 3-4. Flue gas CO and O_2: COW+SA test.

CO levels showed peaks during periods of soot blowing. With the drop in O_2 levels below the critical point, the peaks increased in amplitude, reaching greater than 1,000 ppm with COW+SA, where they had been below 150 ppm with O_2 levels greater than 3.2 percent. From the increased fluctuation in CO levels, it appeared that combustion was less stable and more sensitive to O_2 levels when soda ash was added to the COW mixture.

NO_x emissions were only slightly lowered with soda ash addition. In the COW test NO_x emissions averaged 477 ppm, while NO_x emissions for COW+SA averaged 427 ppm (both at 3 percent O_2, dry). This 10 percent reduction might be attributable to the lower flame temperatures caused by the larger amounts of inert matter in the fuel as shown by the fuel composition data given in Tables 3-3 and 3-4. Although ultimate analysis of the parent fuels were not available, the nitrogen content of this coal was probably on the order of 1 to 1.5 percent since oil generally contains less nitrogen than coal. As shown, the nitrogen content of COW fuels was about 0.75 percent.

SO_2 emissions decreased significantly (over 95 percent) with the addition of soda ash from a total 1,310 ng/J to 51 ng/J (heat input) measured with continuous monitors and from 1,061 ng/J to 14 ng/J measured with the controlled condensation train. Table 3-5 presents results of sulfur mass balance calculations using controlled condensation test data. In the COW test, emitted sulfur accounted for 45 percent more sulfur than was introduced in the fuel. However, in the second (COW+SA) test, they accounted for only 66 percent of the fuel sulfur.

The sulfur imbalance of the COW test may be attributed to an overestimation of the sulfur as sulfates in the particulate sample. The imbalance in the COW+SA test may be attributed to sulfur retained in the

TABLE 3-3. OVERALL FUEL COMPOSITION (PERCENT BY WEIGHT)

	COW	COW+SA
Coal	42	38.6
Oil	42	39.2
Water	16	14.5
Soda ash	--	7.7

TABLE 3-4. ULTIMATE FUEL ANALYSES (PERCENT BY WEIGHT)[a]

	COW	COW+SA
Carbon, C	78.02	71.74
Hydrogen, H	8.60	7.83
Nitrogen, N	0.76	0.73
Sulfur, S	1.93	1.90
Oxygen, O (by difference)	6.69	4.63
Ash	4.00	13.17
Heating value[b] kJ/kg	31,413	26,952
(Btu/lb)	13,491	11,575
Moisture[b]	15.60	15.54

[a]Dry basis, except as noted.
[b]As received.

TABLE 3-5. SULFUR BALANCE (ng/J AS SULFUR)

	COW	COW+SA
Inlet:		
Fuel	614	705
Outlet:		
Flue gas		
SO_2[a]	530.5	7.1
SO_3[a]	0.37	--
Particulate S	>363	458
Total out	894	465
Out/in, percent	145	66

[a]From controlled condensation train.

furnace and firetube deposits as Na_2SO_3 and Na_2SO_4. As discussed earlier, after the COW+SA test, approximately 127 kg (281 lb) of deposits were removed from the boiler. Assuming that 80 percent of these deposits are due to the second test (the remaining 20 percent to the first COW test) and that they have the same sulfur concentration as the particulate flyash (1.2 and 12.6 percent sulfur for the COW and COW+SA tests, respectively), the sulfur mass balances (out/in, Table 3-5) change to 148 percent and 126 percent for the COW and COW+SA tests, respectively.

Table 3-6 presents a comparison of the gas stream measurements where they were recorded by more than one set of instruments. For purposes of consistency, the results obtained by Acurex are used throughout this report,

TABLE 3-6. COMPARISON OF GASEOUS EMISSIONS DATA (DRY)

Emission	COW		COW+SA	
	Adelphi University[a]	Acurex	Adelphi University[a]	Acurex
O_2, percent	3.0	3.3	3.3	3.2
CO_2, percent	14.2	13.6	14.2	13.0
SO_2 ppm as measured	1,524[b]	--	52[b]	--
SO_2, ppm as measured	1,382[c]	1,071	30.2[c]	13.4

[a]Measurements were made wet. Corrected based on moisture contents ranging from 6.5 to 8 percent measured by Adelphi.
[b]Averaged over the entire test duration.
[c]Averaged over the time period the controlled condensation train was sampling.

while the others are used only for comparison. The Adelphi University instruments reported results on a wet basis. These were converted to a dry basis using the Adelphi University continuous monitor water measurements, although later calibration showed these values to be 2 to 2.5 percent low. The only significant discrepancy between the two data sets is in the SO_2 measurements. The Acurex CCS measurements are consistently, and significantly, lower (about 23 percent for the COW test and 55 percent for the COW+SA test) than the Adelphi continuous monitor data.

The particulate concentrations during the COW+SA test measured by Adelphi University personnel using a Method 5 particulate sampling train (3,715 mg/dscm) closely agrees with the SASS result (3,721 mg/dscm). Method 5 tests were only performed for the second test. Particulate

emissions increased during the second test (from the SASS data), as might be expected due to the higher ash input. This increase was significant (100 percent), despite the high ash deposition rate in the boiler.

Table 3-7 shows relative size distribution of the particulate and total ash weight collected by the SASS train. The changes in particulate size distribution between the two tests are substantial. In the COW test, the particulate is about evenly split among the three cut sizes provided by the cyclones. Particulate matter with aerodynamic size less than 1 μm (filter catch) accounts for only 5 percent of the total sample for the COW test. In contrast to this, the COW+SA particulate of less than 1 μm accounts for nearly 70 percent of the total mass collected. While particulate matter collected in the cyclones shows a tendency toward the greater than 10 μm size, the size distribution is heavily offset by the fine particulate in the COW+SA test.

The fact that the particulate for the COW+SA test is comprised of mostly fine (<1 μm) particles should not be too surprising. This would be expected since the soda ash additive was originally in solution in the aqueous phase of the COW.

3.3 TRACE ELEMENT ANALYSIS RESULTS

The SASS train samples from the boiler outlet were analyzed for 73 trace elements using Spark Source Mass Spectrometry (SSMS) and Atomic Absorption Spectroscopy (AAS). Once the trace element concentrations were determined by laboratory analysis, trace element flowrates for flue gas vapor and condensed phases could be computed. Appendix B presents trace element concentrations and flowrates.

TABLE 3-7. PARTICULATE SIZE DISTRIBUTION

SASS catch	COW test		COW+SA test	
	Emissions (ng/J)	Percentage	Emissions (ng/J)	Percentage
>10 μm	303	41.9	388	26.6
3 to 10 μm	207	28.7	17	1.2
1 to 3 μm	176	24.4	50	3.4
(<1μm)	36	5.0	1,002	68.8
Total	722	100.0	1,457	100.0

Table 3-8 summarizes flue gas concentrations measured at greater than method detection limits for either test. Barium, zinc, nickel, iron, manganese, chromium, titanium, calcium, potassium, chlorine, sulfur, phosphorus, silicon, aluminum, magnesium, and, possibly, sodium were detected in concentrations greater than 1 mg/dscm in one or both tests. Of these 16 trace elements, 11 (barium, nickel, iron, titanium, calcium, potassium, phosphorus, silicon, aluminum, magnesium and sodium) were not quantitated because their concentration exceeded the upper quantitation limit for the SSMS analysis.

Table 3-9 summarizes the changes in trace element concentrations measured between tests. This information points out those trace elements whose concentration changed by a factor greater than 3, (the accuracy objective of the Level 1 protocols). With the exception of silver, mercury, platinum, and chlorine, trace elements which had significantly different concentrations (greater by a factor of 3) between the two tests were higher

TABLE 3-8. TRACE ELEMENT EMISSIONS IN THE FLUE GAS

	COW test	COW+SA test
Element	µg/dscm	µg/dscm
Aluminum	>150	>1,200
Antimony	5.0	1.6-3.4
Arsenic	160	88
Barium	>1,200	1,100
Beryllium	12	2.9
Bismuth	14	<0.22
Boron	82	130
Bromine	49	76
Cadmium	1.1	1.1
Calcium	>1,800	>1,100
Cerium	150	66
Cesium	7.7	2.9
Chlorine	150	>3,300
Chromium	>1,100	400
Cobalt	29	9.6
Copper	130	140
Dysprosium	10	2.1
Erbium	5.1	0.93
Europium	3.9	6.2
Fluorine	140	410
Gadolinium	9.9	3.1
Gallium	82	33
Germanium	41	24
Hafnium	2.6	0
Holmium	7.1	1.0
Iodine	4.0	3.1
Iron	>2,700	>5,300
Lanthinum	120	61
Lead	780	930
Lithium	110	33
Lutetium	0.57	0.21
Magnesium	>2,000	>2,300
Manganese	>1,100	400
Mercury	0.47	65-85
Molybdenum	72	100

TABLE 3-8. CONCLUDED

Element	COW test µg/dscm	COW+SA test µg/dscm
Neodymium	50	5.2
Nickel	>1,100	650
Niobium	30	8.5
Phosphorus	>2,000	850
Platinum	1.6	11
Potassium	>1,500	>1,200
Praseodymium	30	3.4
Rubidium	98	76
Samarium	38	5.2
Scandium	110	6.4
Selenium	160	67
Silicon	>1,400	>1,000
Silver	0.60-0.87	9.5
Sodium	>790	>850
Strontium	510	110
Sulfur	9.9×10^5	1.2×10^6
Tantalum	0.89	0
Tellurium	0.45	0.31-0.58
Terbium	3.3	0.41
Thallium	20	8.5
Thorium	34	4-17
Thulium	0.89	0.31
Tin	3.5	3.5
Titanium	>2,000	1,700
Tungsten	5.7	6.3
Uranium	150	57-68
Vanadium	920	680
Ytterbium	6.3	2.1
Yttrium	125	40
Zinc	>1,100	280
Zirconium	250	85

TABLE 3-9. RELATIVE TRACE ELEMENT CONCENTRATIONS BETWEEN THE COW AND COW+SA TESTS

Unable to determine because of large concentration[a]	Within factor of 2[b]	Factor of 2-3[b]	Greater than factor of 3[c]
Barium	Lead	Uranium	Bismuth*
Nickel	Tungsten	Thorium	Mercury
Iron	Europium	Thallium	Platinum
Titanium	Lanthanum	Lutetium	Tantalum*
Calcium	Iodine	Ytterbium	Hafnium*
Potassium	Tellurium	Thulium	Erbium*
Phosphorus	Tin	Cerium	Holmium*
Silicon	Cadmium	Cesium	Dysprosium*
Aluminum	Molybdenum	Antimony	Terbium*
Magnesium	Rubidium	Zirconium	Gadolinium*
Sodium	Bromine	Selenium	Samarium*
	Arsenic	Gallium	Neodymium*
	Germanium	Cobalt	Praseodymium*
	Copper	Fluorine	Silver
	Vanadium		Niobium*
	Boron		Yttrium*
	Sulfur		Strontium*
			Zinc*
			Manganese*
			Chromium*
			Scandium*
			Chlorine
			Beryllium*
			Lithium*

[a]Concentrations exceeded the upper detection limit of the SSMS analysis in either or both tests.

[b]Changes in concentration with a factor of 3 indicated that within the accuracy of the analysis, concentrations in both tests are essentially equal.

[c]A "*" has been used to indicate where the concentration in the COW test exceeded that in the COW+SA test by a factor of 3.

in the COW flue gas sample. The chlorine levels exhibit the largest change (150 μg/dscm increased to >3,300 μg/dscm) from the COW to COW+SA tests. This contrasts with the much smaller change in chlorine content of the fuel from 1 ppm to 2 ppm with addition of soda ash. The high concentrations of chromium, nickel, iron, and silicon measured could be in part due to contamination inherent in the methodologies used. For example, chromium and nickel could come from the stainless steel sampling train parts. In addition, high concentrations of chromium, iron, and silicon may be introduced by the quartz-lined stainless steel Parr bomb used to prepare the SASS sorbent resin for SSMS analysis.

Table 3-10 summarizes the trace element mass balances for all the trace elements detected in the COW test samples. Only iodine, silver, zirconium, cobalt, scandium and fluorine show mass balance ratios exceeding a factor of 3. Sixteen elements were detected in the flue gas but not the fuel, while eight were detected in large concentrations in both fuel and flue gas. Thirty balanced within a factor of 3.

Trace element mass balances for the COW+SA test are summarized in Table 3-11. However, because the large quantity of ash deposited in the boiler was not subjected to trace element analysis, interpretation of trace element mass balance is hindered. This is substantiated by the fact that most mass balance (out/in) figures noted in Table 3-11 are significantly less than unity. Also, because the COW+SA test was of relatively short duration, the exhaust gas concentrations are considered less accurate than those for the COW test. Only 10 elements balanced within a factor of 3 for this test, while 30 of the elements were definitely outside this accuracy range.

TABLE 3-10. TRACE ELEMENT MASS BALANCES: COW TEST

Element	COW fuel (in)(µg/s)	Exhaust gas (out)(µg/s)	Mass balance (out/in)
Aluminum	>2,400	>210	a
Antimony		6.7-7.7	a
Arsenic	480	220	0.47
Barium	2,640	>1,650	>0.62
Beryllium	36	170	0.47
Bismuth		1.9	a
Boron	240	110	0.48
Bromine	84	68	0.80
Cadmium	4.8	1.6	0.34
Calcium	>12,000	>2,500	a
Cerium	120	203	1.7
Cesium	36	108	0.30
Chlorine	120	210	1.7
Chromium	720	>1,500	>2.0
Cobalt	240	41	0.17
Copper	360	180	0.49
Dysprosium		14	a
Erbium		7.1	a
Europium	6	5.5	0.91
Fluorine	840	190	0.22
Gadolinium		14	a
Gallium	120	110	0.95
Germanium	72	57	0.79
Hafnium		3.6	a
Holmium		9.8	a
Iodine	48	5.5	0.12
Iron	>12,000	>3,800	a
Lanthanum	240	165	0.69
Lead	48	1,080	2.3
Lithium	120	150	1.2

[a]Indicates that a mass balance calculation was not posible because concentration of the element in the fuel was less than detectable or the concentration in both input and output streams exceeded the upper detection limit of the analysis.

TABLE 3-10. CONTINUED

Element	COW fuel (in)(μg/s)	Exhaust gas (out)(μg/s)	Mass balance (out/in)
Lutetium		0.79	a
Magnesium	11,000	>2,800	>0.25
Manganese	1,200	>1,500	>1.2
Mercury		0.65	a
Molybdenum	120	100	0.83
Neodymium	72	70	0.97
Nickel	960	>1,400	>1.5
Niobium	60	41	0.68
Phosphorus	4,200	>2,700	>0.65
Platinum		2.3	a
Potassium	>12,000	>2,100	a
Praseodymium	36	41	1.1
Rubidium	240	140	0.57
Samarium	48	53	1.1
Scandium	36	150	4.1
Selenium	360	220	0.61
Silicon	>12,000	>1,900	a
Silver	9.6	0.83-1.2	0.086-0.13
Sodium	>6,100	>1,100	a
Strontium	940	710	0.74
Sulfur	2.7×10^6	1.4×10^6	0.50
Tantalum		1.2	a
Tellurium		0.57-0.68	a
Terbium		4.6	a
Thallium	48	27	0.57
Thorium	48	47-50	1.0
Thulium		1.2	a
Tin	6	4.9	0.81
Titanium	>12,000	>2,700	a
Tungsten		7.9	a

[a]Indicates that a mass balance calculation was not posible because concentration of the element in the fuel was less than detectable or the concentration in both input and output streams exceeded the upper detection limit of the analysis.

TABLE 3-10. CONCLUDED

Element	COW fuel (in)(µg/s)	Exhaust gas (out)(µg/s)	Mass balance (out/in)
Uranium	84	29-210	2.5
Vanadium	1,800	1,300	0.71
Ytterbium		8.8	a
Yttrium	360	170	0.48
Zinc	720	>1,500	>2.0
Zirconium	73	340	4.7

[a]Indicates that a mass balance calculation was not posible because concentration of the element in the fuel was less than detectable or the concentration in both input and output streams exceeded the upper detection limit of the analysis.

TABLE 3-11. TRACE ELEMENT MASS BALANCES: COW+SA TEST

Element	COW+SA (in)(μg/s)	Exhaust gas (out)(μg/s)	Mass balance (out/in)
Aluminum	490	>1,500	>0.032
Antimony		2.1-4.3	a
Arsenic		110	a
Barium	>12,000	1,300	<0.11
Beryllium	27	36	0.15
Bismuth		<0.26	a
Boron	120	160	1.4
Bromine	240	95	0.40
Cadmium		1.4	a
Calcium	>12,000	>1,400	a
Cerium	1,300	84	0.064
Cesium	120	3.7	0.032
Chlorine	240	>410	>17
Chromium	12,000	500	<0.042
Cobalt	12	12	1.0
Copper	590	170	0.29
Dysprosium	47	2.6	0.055
Erbium	<12	1.2	>0.099
Europium	24	0.78	0.033
Fluorine	71	520	7.3
Gadolinium	59	3.9	0.066
Gallium	120	42	0.36
Germanium	110	30	0.28
Hafnium	24		0.0
Holmium	24	1.3	0.055
Iodine		3.9	a
Iron	>12,000	>6,700	a
Lanthanum	1,300	76	0.059
Lead	240	1,200	4.9
Lithium	12	410	3.5

[a]Indicates that a mass balance calculation was not posible because concentration of the element in the fuel was less than detectable or the concentration in both input and output streams exceeded the upper detection limit of the analysis.

TABLE 3-11. CONTINUED

Element	COW+SA (in)(µg/s)	Exhaust gas (out)(µg/s)	Mass balance (out/in)
Lutetium		0.26	a
Magnesium	>12,000	>2,900	<0.090
Manganese	6,200	510	0.083
Mercury		81-110	a
Molybdenum	590	130	0.21
Neodymium	240	6.5	0.028
Nickel	2,000	820	0.41
Niobium	240	11	0.045
Phosphorus	>12,000	>1,300	a
Platinum		13	a
Potassium	>12,000	>1,500	a
Praseodymium	240	4.3	0.018
Rubidium	<83	96	>1.2
Samarium	95	6.5	0.069
Scandium	71	7.8-8.3	0.11
Selenium	590	84	0.14
Silicon	>12,000	>1,300	a
Silver		12	a
Sodium	>12,000	>1,800	a
Strontium	3,400	140	0.041
Sulfur	2.6×10^6	8.5×10^6	3.2
Tantalum			a
Tellurium		0.39-0.73	a
Terbium	24	0.52	0.022
Thallium	<24	11	>0.45
Thorium	470	5.2-22	0.011-0.045
Thulium		0.39	a
Tin		2.8	a
Titanium	>12,000	2,200	<0.18
Tungsten	110	8.0	0.075

[a] Indicates that a mass balance calculation was not posible because concentration of the element in the fuel was less than detectable or the concentration in both input and output streams exceeded the upper detection limit of the analysis.

TABLE 3-11. CONCLUDED

Element	COW+SA (in)	Exhaust gas (out)	Mass balance (out/in)
Uranium	1,700	71-85	0.043-005
Vanadium	8,000	860	0.11
Ytterbum		2.6	a
Yttrium	1,500	51	0.033
Zinc	360	350	0.99
Zirconium	1,400	110	0.076

[a]Indicates that a mass balance calculation was not posible because concentration of the element in the fuel was less than detectable or the concentration in both input and output streams exceeded the upper detection limit of the analysis.

3.4 ORGANIC SPECIES EMISSIONS

Organic analyses were performed on specified flue gas samples according to EPA Level 1 protocol (Reference 3-1) as outlined in Appendix A. Volatile organic species having boiling points in the C_1 to C_6 range of less than 100°C (212°F) were determined by analysis of flue gas grab samples by on-site gas chromatography. The SASS train particulate, organic module sorbent (XAD-2), and organic module condensate samples were extracted with methylene chloride in a Soxhlet apparatus. The extracts were then subjected to total chromatographable organic (TCO) and gravimetric (GRAV) analyses to determine species within the 100° to 300°C (212° to 572°F), and greater than 300°C (572°F) boiling point ranges, respectively. Infrared spectra of the GRAV residue of the extracts were also obtained. The XAD-2 extract samples were subjected to further separation by liquid column chromatography followed by infrared analyses of the resulting fractions and low resolution mass spectrometry analysis of selected fractions. Because the organic content (TCO + GRAV) of other extract samples was less than 15 mg, they were not subjected to further analyses.

3.4.1 Total Organic Analyses

Table 3-12 summarizes organic emissions from the C_1 to C_6, TCO, and gravimetric analyses. Total organic emissions doubled during the second test with the soda ash additive. The largest increases occurred in the nonvolatile organics which have boiling points greater than 300°C (572°F), which tripled from 2.9 mg/dscm to 9.0 mg/dscm. Emissions of semivolatile organics in the boiling-point range of 100° to 300°C (212° to 572°F) were negligible in both tests while the C_1 to C_6 hydrocarbon levels were

TABLE 3-12. SUMMARY OF TOTAL ORGANIC EMISSIONS (mg/dscm)

Organic emissions	COW	COW+SA
Volatile organic gases analyzed in the field by gas chromatography		
C_1	--	--
C_2	0.9	--
C_3	--	--
C_4	2.9	4.1
C_5	--	--
C_6	--	--
Total C_1 - C_6	3.8	4.1
Semivolatile organic material analyzed by TCO		
XAD-2 cartridge	<0.04	<0.2
Organic module condensate	<0.004	<0.002
Total C_7 - C_{16}	<0.04	<0.02
Nonvolatile organic analyzed by gravimetric procedure		
10 + 3 μm cyclones	<0.2	2.0
Filter + 1 μm cyclone	<0.3	2.0
XAD-2 cartridge	2.9	5.0
Organic module condensate	<0.2	<0.7
Total > C_{16}	2.9	9.0
Total organics	6.7	13.1

essentially the same for both tests. For both tests the particulate organic fraction was less than 0.1 percent by weight. For comparison, a recent report on flue gas organic emissions from coal- and oil-fired utility and industrial boilers indicates total organic concentrations in the range of 0.124 to 4.32 mg/dscm (Reference 3-2).

3.4.2 Infrared (IR) Spectra of Total Sample Extracts

The results of the IR spectrometric analyses of total sample extracts are summarized in Table 3-13. IR spectrometry is used to identify the organic functional groups present in the sample. As noted, the XAD-2 extract spectra suggested the presence of oxygenated compounds such as aldehydes, ketones, esters, or carboxylic acids in this sample from both tests. The spectra of both particulate fractions for the COW+SA test were consistent only with the presence of aliphatic hydrocarbons. The spectra of both particulate fractions for the COW test, as well as the OMC extract spectra for both tests, were too weak for interpretation.

3.4.3 LC Fractionation of XAD-2 Extracts

The XAD-2 extracts from both tests were subjected to liquid chromatography separation with GRAV and IR analyses of each fraction. Since the TCO content of both total sample extracts was less than detectable (see Table 3-12), TCO analyses of LC fractions were not performed. Tables 3-14, 3-15, and 3-16 present the results of the LC separation and subsequent IR analyses. Similar LC elution patterns exist for both tests, and the IR results suggest that similar compounds were present for both tests. Essentially all absorbances present in the total sample extract (see Table 3-13) were present in the fractions. Higher total organic levels were found

TABLE 3-13. SUMMARY OF INFRARED SPECTRA OF TOTAL SAMPLE EXTRACTS

Sample	COW test				COW+SA test			
	Wave number (cm^{-1})	Intensity[a]	Possible assignment	Possible *compound* categories present	Wave number (cm^{-1})	Intensity[a]	Possible assignment	Possible *compound* categories present
10 + 3 μm particulate	No peaks				2910	S	CH alkyl	Aliphatic hydrocarbons
					2840	S	CH alkyl	
1 μm + filter particulate	No peaks				2920	S	CH alkyl	Aliphatic hydrocarbons
					2840	S	CH alkyl	
XAD-2 extract	2910	S	CH alkyl	Aliphatic, hydrocarbons, carboxylic acids, and other oxygenates such as aldehydes and ketones	2920	S	CH alkyl	Aliphatic hydrocarbons, carboxylic acids, and other oxygenates such as aldehydes and ketones
	2850	S	CH alkyl		2840	S	CH alkyl	
	1770	S	C=O stretch		1730	M	C=O stretch	
	1450	M	C-H bend					
	1280	S	C-O stretch		1270	W	C-O stretch	
	1130	S	C-O stretch		1070	W	C-O stretch	
	970	M	C-C stretch					
Organic module condensate	No peaks				No peaks			

[a]S: strong, M: moderate, W: weak

TABLE 3-14. LC FRACTION GRAVIMETRIC RESULTS FOR THE COW TEST XAD-2 EXTRACT SAMPLE[a]

Fraction	mg/dscm	ng/J
LC1	0.59	0.22
LC2	0.50	0.18
LC3	0.42	0.15
LC4	<0.08	<0.03
LC5	<0.08	<0.03
LC6	0.25	0.09
LC7	0.13	0.05
Total	1.9	0.69

[a]Based on total organics recovered in each fraction corrected from total sample taken for LC to total organics in the original sample.

TABLE 3-15. LC FRACTION GRAVIMETRIC RESULTS FOR THE COW+SA TEST XAD-2 EXTRACT SAMPLE[a]

Fraction	mg/dscm	ng/J
LC1	<0.2	<0.08
LC2	1.0	0.40
LC3	1.5	0.60
LC4	0.3	<0.12
LC5	<0.2	<0.08
LC6	0.3	0.12
LC7	<0.2	0.08
Total	3.1	1.24

[a]Based on total organics recovered in each fraction corrected from total sample taken for LC to total organics in the original sample.

TABLE 3-16. SUMMARY OF INFRARED SPECTRA OF LC FRACTIONS OF THE XAD-2 EXTRACT SAMPLES

LC fraction	COW test				COW+SA test			
	Wave number (cm^{-1})	Intensity[a]	Possible assignment	Possible compound categories present	Wave number (cm^{-1})	Intensity[a]	Possible assignment	Possible compound categories present
LC1	2920 2840 1740 1270	S S M M	CH alkyl CH alkyl C=O stretch C-O stretch	Aliphatic hydrocarbons, some oxygenates such as aldehydes or carboxylic acids	No peaks			
LC2	No peaks				2920 1730 1270	S S S	CH alkyl C=O stretch C-O stretch	Aliphatic hydrocarbons, some oxygenates such as carboxylic acids
LC3	No peaks				2920-2380 1730 1270	S M M	CH alkyl C=O stretch C-O stretch	Aliphatic hydrocarbons, some oxygenates such as aldehydes or carboxylic acids
LC4	No peaks				No peaks			
LC5	No peaks				No peaks			
LC6	2860 1110-1070	S M	CH alkyl C-O stretch	Oxygenated hydrocarbons such as alkehydes, ketones, or alcohols	No peaks			
LC7	No peaks				No peaks			

[a]S: strong; M: moderate, W: weak

in all LC fractions of the COW+SA samples than their COW counterparts, which is consistent with the TCO and GRAV results on the total sample extracts. The oxygenated compounds suggested could be carboxylic acids, ketones, aldehydes, or alcohols. However, these compounds usually elute in LC4 to LC6 (Reference 3-1), not LC1, LC2, or LC3, where they appeared in these tests.

3.4.4 Low Resolution Mass Spectrometry Analysis of Total Extracts and LC Fractions

Table 3-17 presents the results of low resolution mass spectrometry (LRMS) analysis of those samples which had a total organic (TCO + GRAV) content corresponding to flue gas emissions greater than 0.5 mg/dscm. Table 3-18 lists the compound classes and characteristic fragment ion searched for by direct insertion probe LRMS to identify them. Since the TCO content of the extract samples was negligible, only direct insertion probe LRMS was performed in accordance with Level 1 procedures. In addition to the compound classes found and noted in Table 3-17, there existed a background level of aliphatic hydrocarbons in all samples. The LRMS data agree with the IR insofar as detecting aliphatic hydrocarbons. However, where IR indicated the presence of various organic oxygenated compounds in the XAD extract, LRMS analysis generally did not confirm such findings. The LRMS analysis of the filter + 1 μm particulate from the COW+SA test did, however, indicate the presence of phenols.

Tables 3-19 and 3-20 summarize organic analysis results for the COW and COW+SA tests, respectively. The top portion of each table summarizes the TCO and GRAV analyses of the organic sorbent XAD-2 extracts eluted in the seven liquid chromatography fractions (LC). The bottom portions of the tables summarize the organic categories found in the samples using low resolution

TABLE 3-17. SUMMARY OF LRMS ANALYSES

Test	Sample	Chemical class found[a]
COW	XAD LC fraction 1	Aliphatic hydrocarbons
	XAD LC fraction 2	None
	XAD LC fraction 3	None
COW+SA	XAD LC fraction 1	Aliphatic hydrocarbons
	XAD LC fraction 2	None
	XAD LC fraction 3	None
	10 μm + 3 μm particulate total extract	Aliphatic hydrocarbons
	1 μm + filter particulate total extract	Aliphatic hydrocarbons Phenols

[a]General background of aliphatic hydrocarbons throughout all samples.

TABLE 3-18. COMPOUND CLASSES AND FRAGMENT IONS SEARCHED FOR BY DIRECT INSERTION PROBE LRMS

Compound class	Fragment ions (m/e^-)
Aliphatic hydrocarbons	57,71,85
Halogenated aliphatics	63,65
Polycyclic aromatics	178,202,228,252
Halogenated ethers	63,65,73
Alcohols	75,89,103
Phenols	51,77,94
Halogenated phenols	162,196
Nitrophenols	139
Phthalate esters	149,167
Amines	84,98
Nitrosamines	44,58
N-heterocyclics	167,193
Mercaptans	47,61
Sulfides	75,89,103
Benzothiophenes	134
Carboxylic acids	60,73
Carboxylic acid esters	74,87

TABLE 3-19. ORGANIC EXTRACT SUMMARY - COW XAD-2 EXTRACT

	LC1	LC2	LC3	LC4	LC5	LC6	LC7	Total
Total organics, mg	14	12	10	<2	<2	6	3	45
TCO, mg						-		<1
GRAV, mg	14	12	10	<2	<2	6	3	45

	Assigned intensity -- mg/dscm							
Category	LC1	LC2	LC3	LC4	LC5	LC6	LC7	Total
Aliphatic HC's[a]	100-0.59							0.59
Aldehydes, ketones, acids		100-0.50	100-0.42				100-0.13	1.05
Alcohols						100-0.25		0.25

[a]Aliphatic background present in all LRMS samples.

TABLE 3-20. ORGANIC EXTRACT SUMMARY - COW+SA XAD-2 EXTRACT

	LC1	LC2	LC3	LC4	LC5	LC6	LC7	Total
Total organics, mg	<1	6	9	2	<1	2	<1	19
TCO, mg								<1
GRAV, mg	<1	6	9	2	<1	2	<1	19

	Assigned intensity -- mg/dscm							
Category	LC1	LC2	LC3	LC4	LC5	LC6	LC7	Total
Aliphatic HC's[a]		100-0.5	100-0.8					1.3
Aldehydes, ketones, acids		100-0.5	100-0.7	100-0.3		100-0.3		1.8

[a]Aliphatic hydrocarbons background present in all LRMS samples.

mass spectromety (LRMS), as supplemented by inferences from the IR analyses, and their estimated concentrations based on the total organic level in the samples. The conclusions to be drawn from these data are:

- Aliphatic hydrocarbons are definitely present as indicated by IR and LRMS of both COW and COW+SA samples
- Aldehydes, ketones, or carboxylic acids are probably present as long chains since they were detected in LC2 and LC3 (not LC4 or LC6) and are unconfirmed by LRMS
- Alcohols may be present in the COW XAD-2 extract since they were suggested by the IR analysis of LC6

3.4.5 Gas Chromatography/Mass Spectrometry (GC/MS) Analysis for POM and Other Organic Compounds

Gas Chromatography/Mass Spectrometry (GC/MS) analyses of the SASS extracts (10 μm + 3 μm particulate, 1 μm + filter particulate, XAD-2, and organic module condensate) were performed to detect and quantify specific polycyclic organic (POM) and other organic compounds (the semivolatile organic priority pollutant species). The compounds sought in the analysis and their respective detection limits are listed in Table 3-21. Table 3-22 lists the concentrations of the compounds detected in the various extracts. With the exception of the XAD-2, all the extracts showed POM at or below the detection limits. The phenanthrene and fluoranthene concentrations detected in the COW test, at 0.1 and 0.05 μg/dscm, respectively, are somewhat less than the concentration of phenanthrene detected in the COW+SA test (0.7 μg/dscm). This observation is consistent with the fact that the COW+SA flue gas samples had higher levels of total organic content than those for the COW test.

TABLE 3-21. COMPOUNDS SOUGHT IN THE GC/MS ANALYSIS AND THEIR DETECTION LIMITS (ng/μl INJECTED)

Acid Compounds			
2,4,6-trichlorophenol	5	2-nitrophenol	5
p-chloro-m-cresol	5	4-nitrophenol	20
2-chlorophenol	5	2,4-dinitrophenol	20
2,4-dichlorophenol	5	4,6-dinitro-o-cresol	20
2,4-dimethylphenol	5	pentachlorophenol	5
		phenol	1
Base Neutral Compounds			
1,2,4-trichlorobenzene	1	benzo(c)phenathrene	40
1,2-dichlorobenzene	1	bis(2-chloroethoxy)methane	1
1,2-diphenylhydrazine (as azobenzene)	1	bis(2-chloroethyl)ether	1
		bis(2-chloroisopropyl)ether	1
1,3-dichlorobenzene	1	bis(2-ethylhexyl)phthalate	1
1,4-dichlorobenzene	1	butyl benzyl phthalate	1
2,4-dinitrotoluene	1	chrysene	1
2,6-dinitrotoluene	1	di-n-butyl phthalate	1
2-chloronaphthalene	1	di-n-octyl phthalate	1
3,3'-dichlorobenzidine	5	dibenzo(a,h)anthracene	5
3-methyl cholanthrene	40	dibenzo(c,g)carbazole	40
4-bromophenyl phenyl ether	1	diethyl phthalate	1
4-chlorophenyl phenyl ether	1	dimethyl phthalate	1
7,12-dimethyl benz(a)anthracene	40	fluoranthene	1
N-nitrosodi-n-propylamine	5	fluorene	1
N-nitrosodimethylamine	NA	hexachlorobenzene	1
N-nitrosodiphenylamine	1	hexachlorobutadiene	1
acenaphthene	1	hexachlorocyclopentadiene	1
acenaphythylene	1	hexachloroethane	1
anthracene	1	indeno(1,2,3-cd)pyrene	5
benzo(ghi)perylene	5	isophorone	1
benzidine	20	naphthalene	1
benzo(b)fluoranthene	1	nitrobenzene	1
benzo(k)fluoranthene	1	perylene	40
benzo(a)anthracene	1	phenanthrene	1
benzo(a)pyrene	1	pyrene	1

TABLE 3-22. COMPOUNDS DETECTED IN GC/MS ANALYSIS AND THEIR CONCENTRATIONS (μg/dscm)

	COW test				
	10 μm + 3 μm cyclones	Filter + 1 μm cyclone	XAD-2 extract	OMC	Total
Fluoranthene	<0.05	<0.07	0.05	<0.04	0.05
Phenanthrene	<0.05	<0.07	0.1	<0.04	0.1
Other polynuclears	<0.05	<0.07	<0.05	<0.04	<0.07
	COW+SA test				
	10 μm + 3 μm cyclones	Filter + 1 μm cyclone	XAD-2 extract	OMC	Total
Phenanthrene	<0.3	<0.3	0.7	<0.2	0.7
Other polynuclears	<0.3	<0.3	<0.2	<0.2	<0.3

TABLE 3-23. PARTICULATE/RADIOMETRIC ACTIVITY (pCi/g SAMPLE)[a]

	Alpha	Beta	Gamma
COW test			
10 μm + 3 μm	196.7 ± 20.0	79.3 ± 11.3	183 ± 292
1 μm + filter	224.1 ± 47.7	128.8 ± 38.6	553 ± 300
COW+SA test			
10 μm + 3 μm	93.7 ± 8.5	40.5 ± 14.7	219 ± 293
1 μm + filter	24.8 ± 4.8	16.3 ± 2.9	100 ± 290

[a]The ± values are the 2 sigma Poisson standard deviation of the counting error

3.5 RADIONUCLIDES

Radiometric activities of the particulate catch from the SASS train cyclones and filter are presented in Table 3-23. Alpha plus beta activities were converted to the emission rates shown in Table 3-24. For comparison, the radionuclide emissions (excluding radon) calculated for a new and an older coal-fired power plant are 0.17 and 0.80 pCi/g of fuel, respectively (Reference 3-3). While the COW and COW+SA emissions are higher by factors of 40 and 16 than the new powerplant model cases, it should be noted that the models represent emissions after control devices, while the measurements for these tests were taken from the uncontrolled gas stream coming directly from the boiler. Thus, these results can be considered within the normal range associated with coal combustion.

TABLE 3-24. RADIOMETRIC EMISSIONS[a]

	Emission rate	
Test	pCi/s	pCi/g fuel
COW	817	6.78
COW+SA	314	2.63

[a]Alpha plus Beta only.

REFERENCES FOR SECTION 3

3-1. Lentzen, D.E., et.al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition)", EPA 600/7-78-201, NTIS PB293795, October 1978.

3-2. Waterland, L.R., et al., "Environmental Assessment of Stationary Source NO_x Control Technologies -- Final Report," EPA-600/7-82-034, NTIS PB82-249350, May 1982.

3-3. "Radiological Impact Caused by Emissions of Radionuclides into the Air in the United States -- Preliminary Report," EPA 520/7-79-006, NTIS PB80-122336, August 1979.

SECTION 4

ENVIRONMENTAL ASSESSMENT

This section discusses the potential environmental significance of the boiler tested, including results of the bioassay testing of samples collected during the tests. As a means of ranking species discharged for possible further consideration, flue gas stream species concentrations are compared to occupational exposure guidelines. Bioassay analyses were conducted as a more direct measure of the potential health effects of the emission stream. Both these analyses are aimed at identifying problem areas and providing the basis for ranking of pollutant species and discharge streams for further consideration.

4.1 EMISSIONS ASSESSMENT

To obtain a measure of the potential significance of the discharge streams analyzed in this test program, discharge stream concentrations were compared to an available set of health-effects-related indices. The indices used for comparison were occupational exposure guidelines. Two sources of such guidelines were used: the time-weighted-average Threshold Limit Values (TLV's) defined by the American Conference of Governmental Industrial Hygienists (ACGIH) (Reference 4-1) and 8-hr time-weighted-average exposure limits established by the Occupational Safety and Health Administration (OSHA) (Reference 4-2).

The comparisons of discharge stream species concentrations to these indices should be used only for ranking species emission levels for further testing and analyses.

Table 4-1 lists those pollutant species emitted in the flue gas discharge stream at levels greater than 10 percent of their occupational exposure guideline for either the COW or the COW+SA test. As noted in the table, several trace elements were present in the boiler outlet for either or both tests at significant levels. However, flue gas particulate accounts for the major fraction of these elements in the flue gas at this location. Ultimate flue gas discharge concentrations would be significantly reduced after passage through a particulate control device.

For comparison, the gaseous criteria pollutants SO_2 and NO_x were emitted at levels over 100 times their occupational exposure guidelines. NO_x emissions were at levels about 150 times its occupational exposure guideline. SO_2 emissions for the COW test were almost 600 times its occupational exposure guideline. Emissions of SO_2 were decreased significantly using the soda ash additive, while changes in emission levels of other species were less substantial. The data in Table 4-1 suggest that the most significant environmental affect of soda ash addition for SO_2 control would be the attendant reduction in SO_2 emissions.

4.2 BIOASSAY RESULTS

Health effects bioassay tests were performed on the organic sorbent (XAD-2) extracts by the SASS train for both tests. A detailed description of the biological analyses performed is presented in Volume II (Data Supplement) of this report. The bioassay tests performed (Reference 4-3) were:

TABLE 4-1. FLUE GAS POLLUTANTS EMITTED AT CONCENTRATIONS EXCEEDING 10 PERCENT OF THEIR OCCUPATIONAL EXPOSURE GUIDELINE

Pollutant	Flue gas concentration (mg/dscm)		Occupational exposure guideline[a] (mg/m^3)
	COW test	COW+SA test	
SO_2	2,900	36	5.0
NO_x	900	830	6.0
Chromium, Cr	>1.1	0.40	0.050
Barium, Ba	>1.2	1.1	0.50
Phosphorus, P	>2.0	0.85	0.10
Lead, Pb	0.78	0.93	0.050[b]
Vanadium, V	0.92	0.68	0.050
Arsenic, As	0.16	<0.089	0.010[b]
Nickel, Ni	>1.1	0.65	0.10
CO	29	490	55
Beryllium, Be	0.012	0.0028	0.0020
Iron, Fe	2.7	5.3	1.0
Platinum, Pt	0.0016	0.011	0.0020
Lithium, Li	0.11	0.033	0.025
Uranium, U	0.15	<0.068	0.050[b]
SO_3	2.0	--	1.0
Fluorine, F	0.14	0.41	0.20[b]
Copper, Cu	0.13	0.14	0.10[b]
Zinc, Zn	>1.1	0.28	1.0
Chlorine, Cl	0.15	3.3	3.0
Silver, Ag	<0.00087	0.0095	0.010
Calcium, Ca	>1.8	>1.1	2.0
Mercury, Hg	0.00047	<0.085	0.10
Selenium, Se	0.16	0.067	0.20
Potassium, K	>1.5	>1.2	2.0[c]
Cobalt, Co	0.029	<0.0097	0.050
Sodium, Na	>0.79	>0.85	2.0[c]
Magnesium, Mg	>2.0	>2.3	10
Manganese, Mn	>1.1	0.41	5.0[c]
Titanium, Ti	>2.0	1.7	10[d]
Thallium, Tl	0.020	0.0085	0.10
Silicon, Si	>1.4	>1.0	10[d]
Yttrium, Y	0.13	0.040	1.0
Biomine, Bi	0.049	0.076	0.70

[a]Time-weight-average TLV (Reference 4-1) unless noted.
[b]8-hr time-weight-average OSHA exposure limit (Reference 4-2).
[c]Ceiling limit.
[d]For nuisance particulate.

- Ames assay, based on the property of Salmonella typhimurium mutants to revert due to exposure to various classes of mutagens
- Cytotoxicity assay (CHO) with mammaliam cells in culture to measure cellular metabolic impairment and death resulting from exposure to soluble toxicants

The results of these assays are summarized in Table 4-2. As noted in the table, the XAD-2 extract from the COW test exhibited moderate to high mutagenicity, and moderate toxicity. The XAD-2 extract from the COW+SA test was of high mutagenicity. The toxicity of this sample in the CHO assay could not be absolutely determined due to limited sample quantity. However, toxicity was determined to be moderate or less. These are common bioassay responses for combustion source XAD-2 extracts. Current studies are investigating whether such bioassay responses are due to artifact compounds formed when combustion product gas containing NO_x is passed over XAD-2 resin.

4.3 SUMMARY

A comprehensive emissions testing program was performed on a 4.1 MW (14 million Btu/hr) industrial boiler while burning a coal-oil-water (COW) mixture, and while burning COW with soda ash (sodium carbonate) (COW+SA) added for SO_2 control. Evidence of furnace fouling was seen when burning the COW fuel in the form of a steadily increasing stack temperature. The rate of fouling increased rapidly when soda ash was added to the fuel. In fact the COW+SA test burn had to be terminated after 3.5 hours.

SO_2 emissions were decreased almost 99 percent with the soda additive, from 1,089 to 13.6 ppm at 3 percent O_2 (based on controlled condensation

TABLE 4-2. XAD-2 EXTRACT BIOASSAY RESULTS

Test	Bioassay	
	Ames[a]	CHO[b]
COW	M/H	M
COW+SA	H	≤M

[a]H = high mutagenity; M = moderate mutagenity.
[b]M = moderate toxicity; ≤M = absolute toxicity could not be determined due to limited sample size, but toxicity moderate or less.

system measurements). NO_x emissions also decreased slightly from 477 to 427 ppm (3 percent O_2). This slight reduction is attributed to the lowered flame temperature attendant to the addition of the inert additive to the fuel. CO emissions increased from an average of 25 ppm in the COW test to 426 ppm in the COW+SA test.

Particulate levels were also higher at the boiler outlet, as expected, with additive addition (1,970 mg/dscm for the COW test to 3,715 mg/dscm for the COW+SA test). The particle size distribution at the boiler outlet shifted from 95 percent greater than 1 μm diameter for the COW test to almost 70 percent less than 1 μm for the COW+SA test. This is consistent with the COW+SA fuel containing significant dissolved solids (the soda ash additive).

Total organic emissions increased from 6.7 mg/dscm to 13.1 mg/dscm with the soda ash additive. This increase was mostly in the nonvolatile fraction (boiling point >300°C, or C_{16+} organic) emissions of which increased from 2.9 to 9.0 mg/dscm. Volatile organics (C_1 to C_6 compounds with boiling points

nominally less than 100°C) emissions remained relatively constant at about 4 mg/dscm. Negligible amounts of semivolatile organics (<40 µg/dscm) were emitted in both tests. Aliphatic hydrocarbons appeared to be the predominant compound category comprising the emitted organics, although the presence of oxygenates such as carboxylic acids, aldehydes, ketones, and alcohols was indicated.

Of the semivolatile organic priority pollutant species analyzed, only phenanthrene and fluoranthene at respective levels of 0.1 and 0.05 µg/dscm were detected in the COW test flue gas samples; only phenanthiene was found in the COW+SA test samples, though at a significantly higher level of 0.7 µg/dscm.

REFERENCES FOR SECTION 4

4-1. "Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment with Intended Changes for 1983-84," American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1983.

4-2. OSHA Safety and Health Standards, 29 CFR 1910, Subpart Z.

4-3. Brusick, D. J., and R. R. Young, "IERL-RTP Procedures Manual: Level 1 Environmental Assessment, Biological Tests," EPA-600/8-81-024, NTIS PB81-228766, October 1981.

APPENDIX A

TEST EQUIPMENT AND PROCEDURES

A.1 CONTINUOUS MONITORING SYSTEM

Rack-mounted monitors and recorders located in a mobile emission laboratory were used for continuous measurement of NO_x, CO, CO_2, and O_2. Figure A-1 illustrates the continuous flue gas extractive sampling system and monitors arrangement. Flue gas is drawn through an in-stack filter and a heated stainless steel probe to a gas conditioning and refrigeration system designed to remove water. The gas conditioning system permits water dropout without scrubbing of water soluble NO_2 from the gas. An unheated line is then used to bring the conditioned gas to the monitors. Calibration gases were used to monitor and correct the drift in the instruments. The calibration gases follow the same path as the flue gas being monitored in that both are conditioned at the stack prior to analysis. Table A-1 lists the instrumentation constituting the continuous monitoring and flue gas extractive sampling system used in this test program.

The Adelphi University continuous monitoring system consists of a Perkin-Elmer multiple gas analyzer MGA-1200 which uses mass spectrometry to measure gas concentrations. Table A-2 lists the short form specifications of the MGA-1200. Samples were taken from the flue gas after it leaves the boiler approximately once per minute and the results (H_2O, O_2, CO_2, N_2 and SO_2) output through a data acquisition computer.

1. In situ filter 0.6μ, 99.999 percent efficient
2. Duct
3. 316 stainless steel probe
4. Four pass conditioner-dryer, 316 stainless steel internals
5. 3/8-inch unheated Teflon
6. Teflon-lined sample pump
7. 3/8-inch unheated Teflon
8. Rotameter
9. 1/4-inch Teflon tubing
10. Calibration gas manifold
11. Calibration gas selector valve
12. Calibration gas cylinders
13. Backpressure regulator
14. Auxillary analysis port

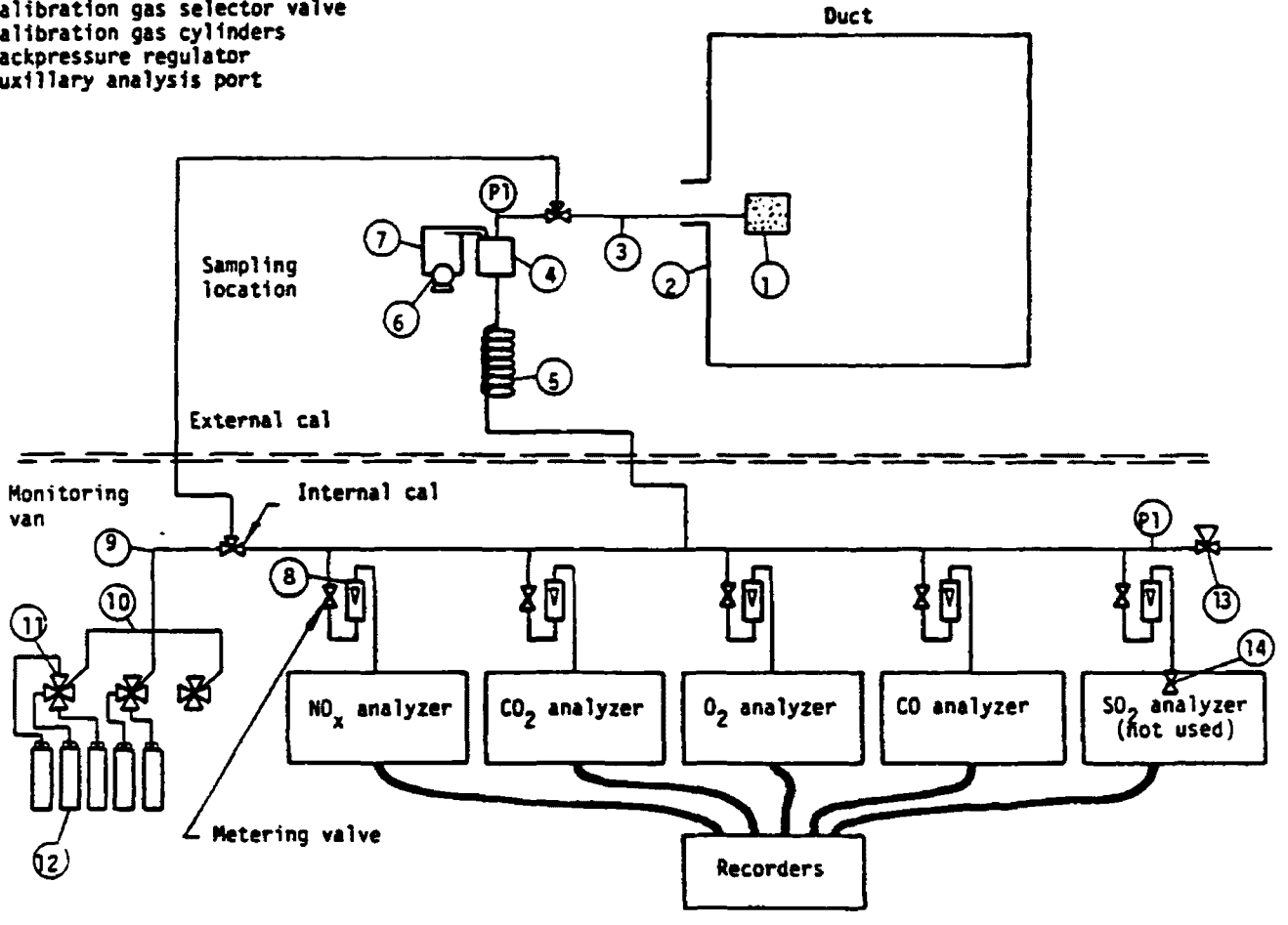


Figure A-1. Schematic of the continuous monitoring system.

TABLE A-1. CONTINUOUS MONITORING EQUIPMENT IN THE MOBILE LABORATORY

Instrument	Principle of operation	Manufacturer	Instrument model	Range
NO NO_x	Chemiluminescence	Thermo Electron	10 AR	0-100 ppm 0-500 ppm 0-1,000 ppm 0-5,000 ppm
CO	Nondispersive infrared (NDIR)	ANARAD	500R	0-1,000 ppm
CO_2	Nondispersive infrared (NDIR)	ANARAD	AR500	0-20 percent
O_2	Fuel cell	Teledyne		0-5 percent 0-25 percent
Sample gas conditioner	Refrigerant dryer-condenser	Hankinson	E-4G-SS	10 scfm
Strip chart recorder	Dual pen analog	Linear	400	0-10 mV 0-100 mV 0-1V 0-10V

TABLE A-2. SPECIFICATIONS OF ADELPHI CONTINUOUS MONITOR

Calibration accuracy	±0.1 percent
Drift	±0.1 percent per hour
Response time	<1 sec for 0 to 90 percent response 10 sec for 99.9 percent response
Sample inlets	2
Gas measured	Range
H_2	0 to 20 percent
O_2	0 to 20 percent
CO_2	0 to 20 percent
N_2	0 to 100 percent
SO_2	0 to 10 percent

A.2 PARTICULATE TESTS

A particulate mass emission measurement during the COW+SA test was performed by Adelphi University personnel for the COW+SA test. The emission test was similar to EPA Method 5 except that an equal radii rather than an equal area traverse was used. Condensible particulate matter was not reported. A schematic of the Method 5 sampling train is shown in Figure A-2.

A.3 SULFUR EMISSIONS

Sulfur emissions (SO_2 and SO_3) were measured using the controlled condensation system illustrated in Figure A-3. This sampling system, designed primarily to measure vapor phase concentrations of SO_3 as H_2SO_4, consists of a heated Vycor probe, a modified Graham condenser (condensation coil), impingers, a pump, and a dry gas test meter. By using the modified Graham condenser, the gas is cooled to the dew point where SO_3 condenses as H_2SO_4. SO_2 interference is prevented by maintaining the temperature of the gas above the water dew point. Sulfur dioxide is collected in a 3 percent hydrogen peroxide solution. Both SO_2 and SO_3 (as H_2SO_4) are measured by titration with a 0.02 N NaOH using bromophenol blue as the indicator. A more detailed discussion of the sampling and analytical techniques for the controlled condensation system is given in Reference A-1.

A.4 TRACE ELEMENT AND ORGANIC EMISSIONS

Emissions of inorganic trace elements and organic compounds were sampled with the Source Assessment Sampling System (SASS). Designed and built for EPA's Process Measurement Branch for Level 1 environmental assessment (Reference A-2), the SASS collects large quantities of gas and solid samples

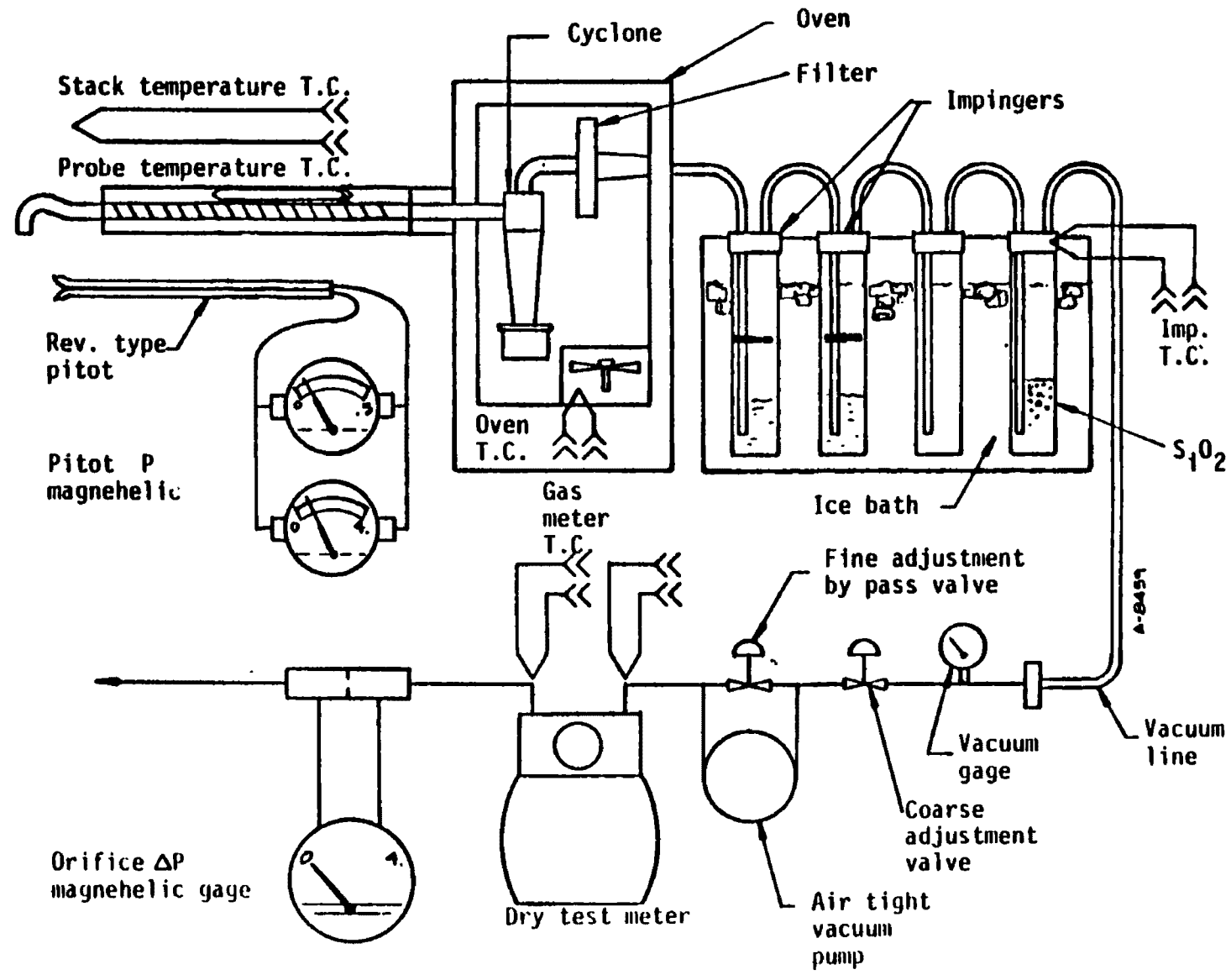


Figure A-2. Particulate sampling train schematic.

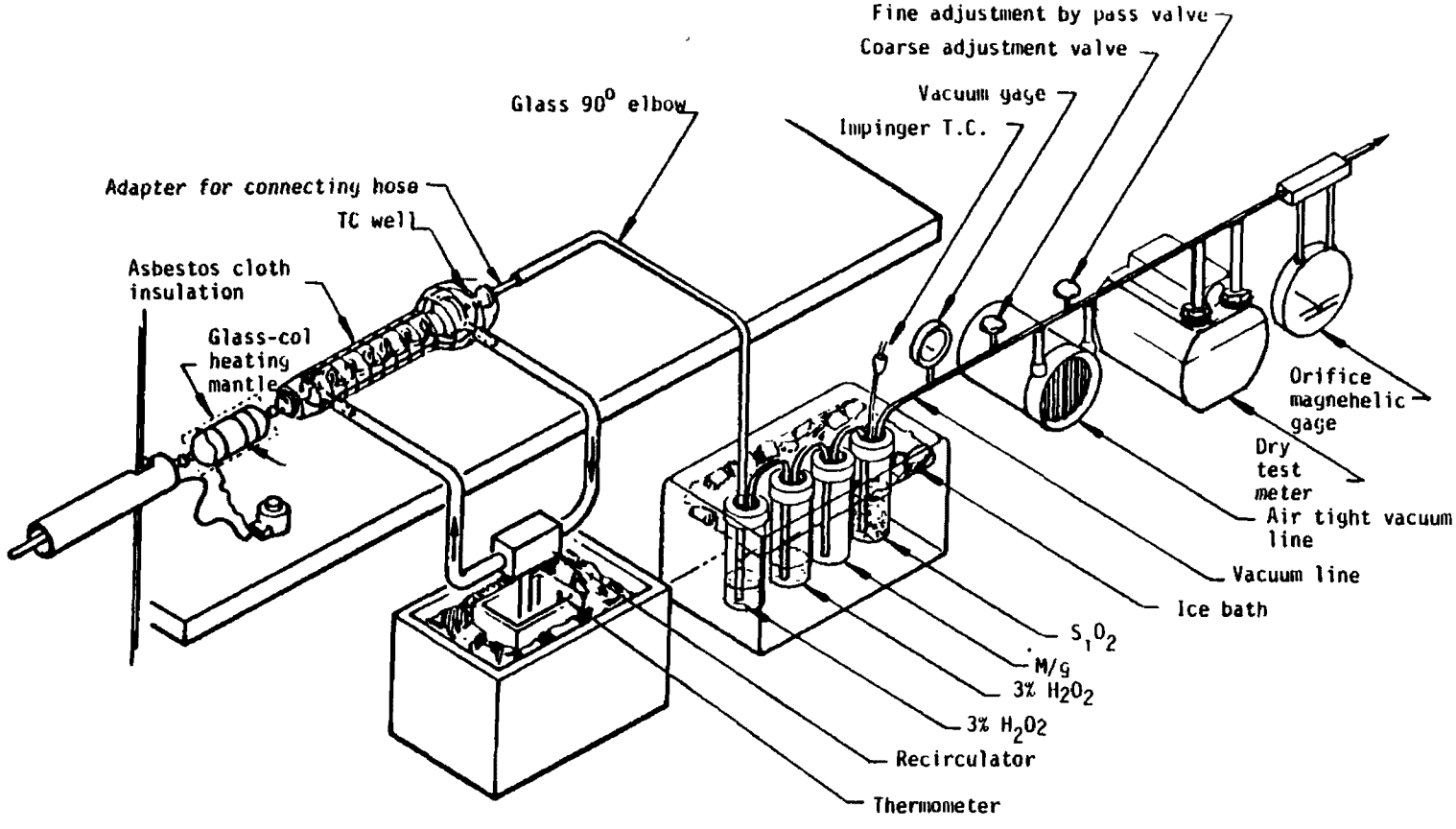


Figure A-3. Controlled condensation system schematic.

required for subsequent analyses of inorganic and organic emissions as well as particle size measurement.

The SASS system, illustrated in Figure A-4, is generally similar to the system utilized for total particulate mass emission tests with the exception of:

- Particulate cyclones heated in the oven with the filter to 230°C (450°F)
- The addition of a gas cooler and organic sampling module
- The addition of necessary vacuum pumps

Schematics outlining the sampling and analytical procedures using the SASS equipment are presented in Figures A-5 and A-6.

Inorganic analyses of solid and liquid samples from the SASS train were performed with Spark Source Mass Spectroscopy (SSMS) for most of the trace elements. Atomic Absorption Spectrometry (AAS) was used for analyses of mercury (Hg), antimony (Sb), and arsenic (As).

Quantitative information on total organic emissions was obtained by gas chromatography for total chromatographable organics (TCO) and by gravimetry (GRAV) of methylene chloride extracts of particulate samples and samples collected in the sorbent module (XAD-2) and condensate trap. Infrared Spectroscopy (IR) and Gas Chromatography/Mass Spectroscopy (GC/MS) were used for identification of organic functional groups and polycyclic organic matter (POM) and other organic species (the semivolatile organic priority pollutant compounds) in SASS sample extracts. Liquid Chromatography (LC) of extract samples containing more than 15 mg total organic into seven polarity fractions, followed by GRAV and IR analyses, and analysis by Low Resolution Mass Spectrometry (LRMS) of fractions containing >0.5 mg/dscm were performed

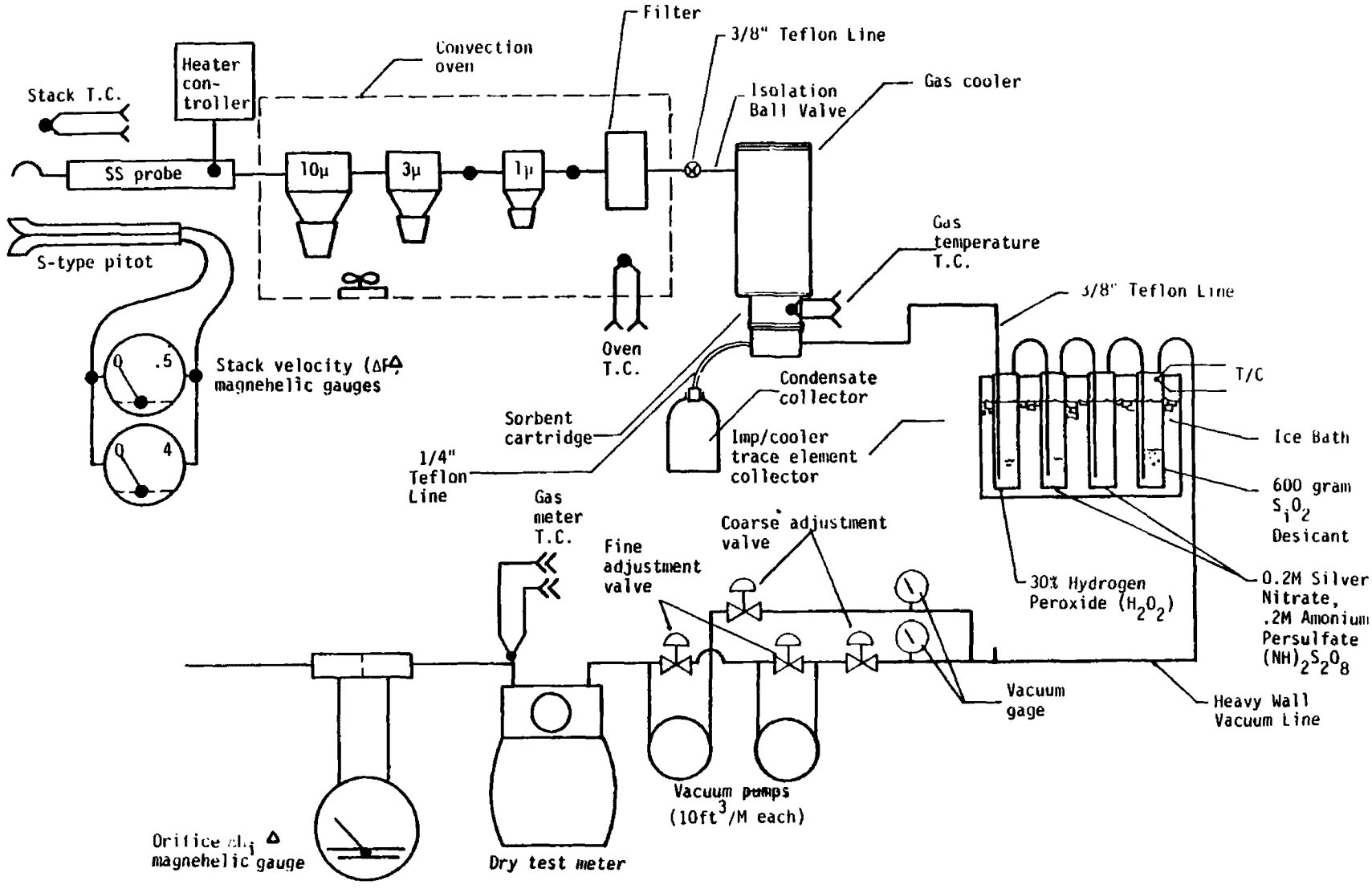
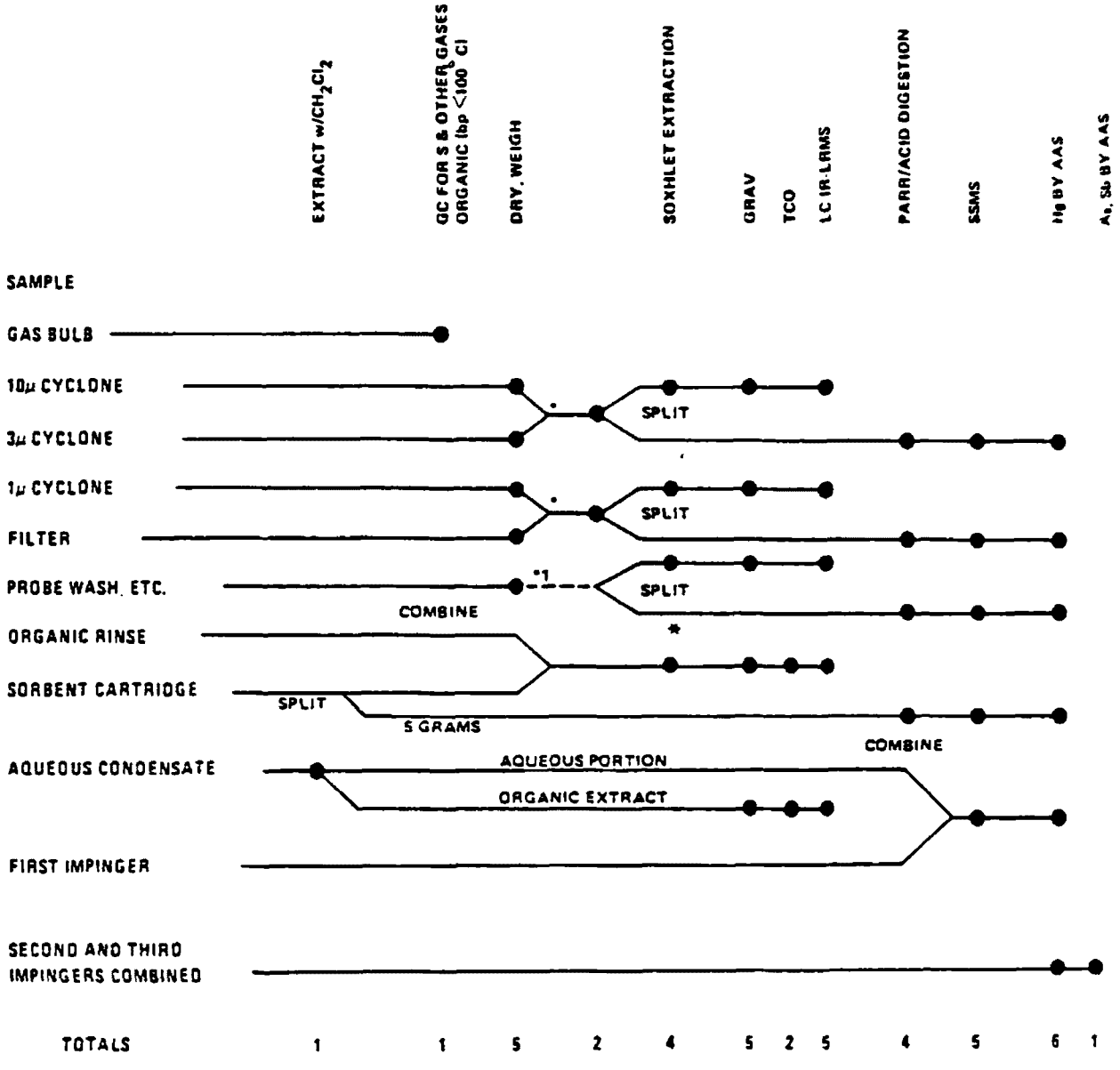


Figure A-4. Source Assessment Sampling Train Schematic



* If required, sample should be set aside for biological analysis at this point.

[1] This step is required to define the total mass of particulate catch. If the sample exceeds 10% of the total cyclone and filter sample weight proceed to analysis. If the sample is less than 10% of the catch, hold in reserve.

Figure A-5. Analysis protocol for SASS samples.

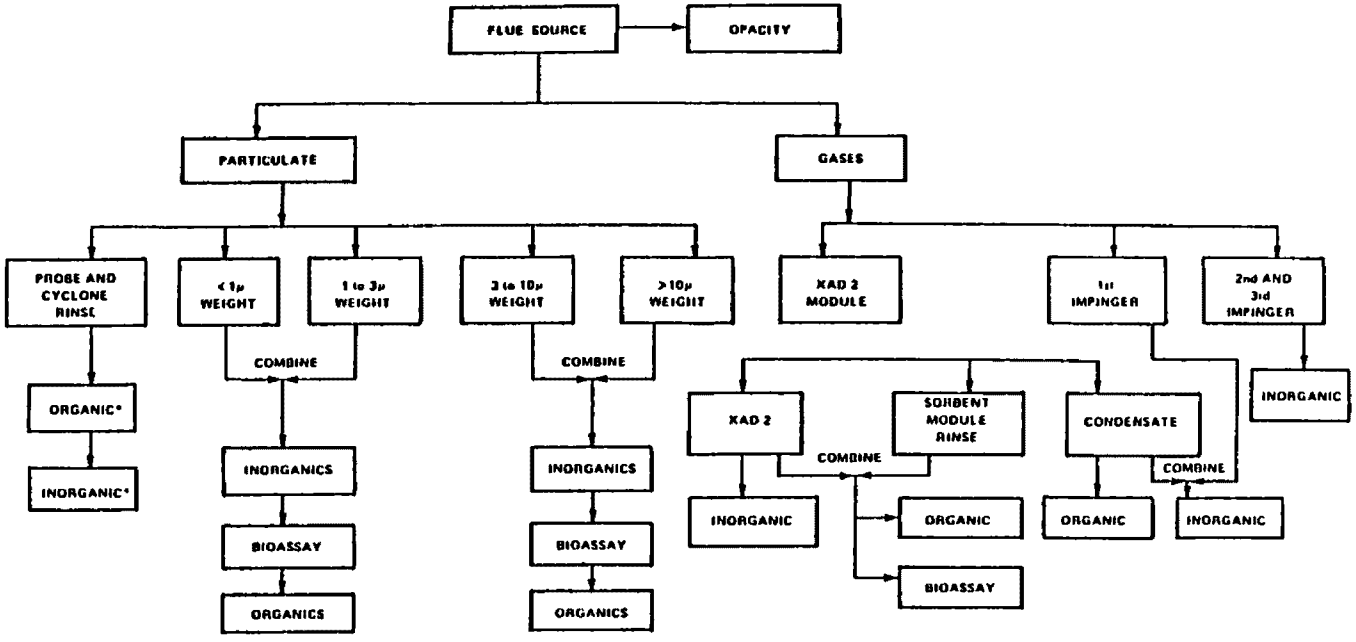


Figure A-6. Flue gas analysis protocol.

to better identify and quantitate specific organic categories present. Figure A-7 illustrates the organic analysis methodology followed during the current program.

Passivation of the SASS train with 15 percent by volume HNO_3 solution was performed prior to equipment preparation and sampling to produce biologically inert surfaces. Detailed description of equipment preparation, sampling procedures, and sample recovery are discussed in Reference A-2 and will not be repeated here. These procedures were followed in the course of the current test program.

A.5 C_1 TO C_6 HYDROCARBON SAMPLING AND ANALYSIS

Acurex used a grab sampling procedure in order to obtain samples of flue gas for C_1 to C_6 hydrocarbon analysis. Samples of the flue gas were extracted using a heated glass probe (Figure A-8). The probe was attached to a heated 250-ml gas sampling bulb. The probe was maintained at 150°C (302°F) and the gas sampling bulb at 130°C (266°F). A diaphragm pump was used to pull samples through the probe and sampling bulb. This purge was continued until all visual signs of condensation had disappeared. At that time, the back stopcock of the sampling bulb was closed and the pump was disconnected. Once the sampling bulb pressure had come to equilibrium with the stack pressure, the sample was sealed and transported to the onsite laboratory for analysis.

The gas sampling bulbs were equipped with septum ports. A gas-tight syringe was used to extract a measured amount of sample. Samples were analyzed on a gas chromatograph (GC) with a flame ionization detector (FID). Both methane and nonmethane hydrocarbons were measured with each injection using a Varian Model 3700 GC with FID, automatic injection loop, and an

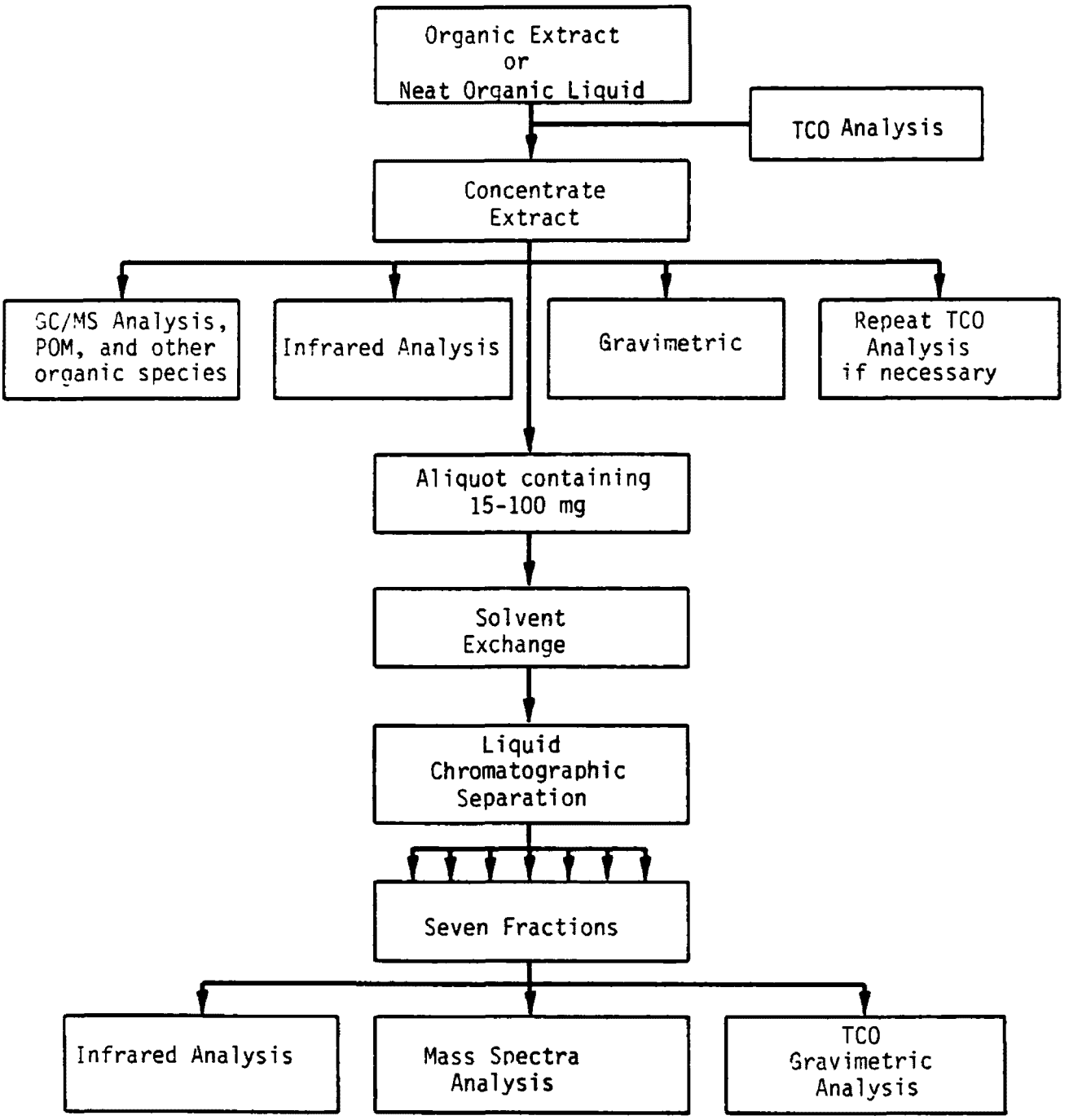
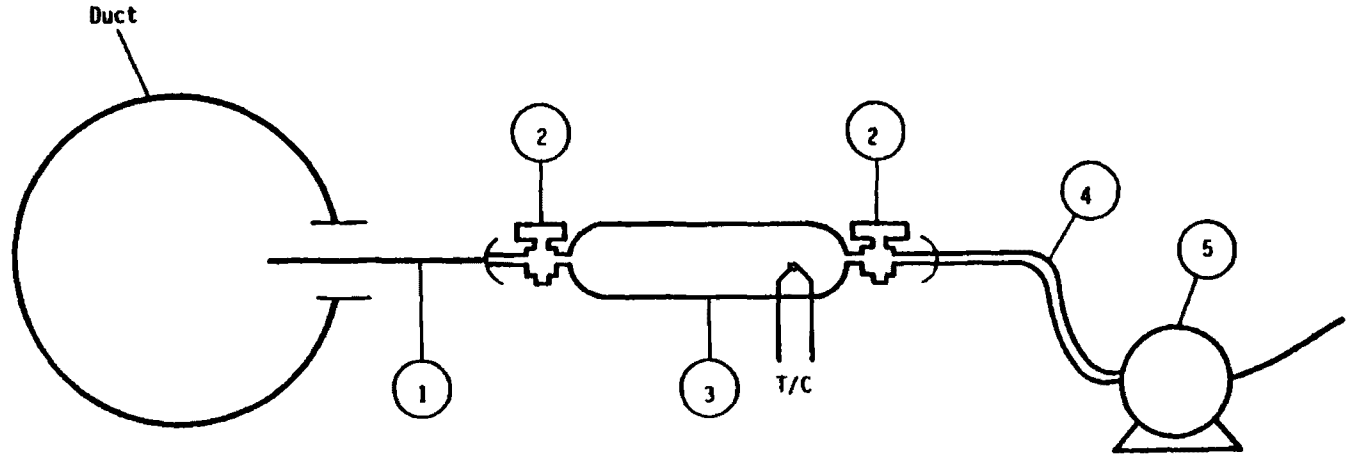


Figure A-7. Organic analysis methodology.



1. Heated glass probe
2. Teflon stopcock
3. 250-ml heated glass gas sampling bulb
4. Tubing connection
5. Sample pump (1 cfm)

Figure A-8. C_1 to C_6 hydrocarbon sampling system.

automatic linear temperature programming capability located onsite. Table A-3 details the instrument specifications.

The GC was calibrated before and after each test in order to determine instrument drift. Blank samples were also run in order to quantify any sampling equipment interferences.

Sample data were recorded continuously on a strip chart recorder. After the detection of the methane peak, the column was back-flushed to the detector for analysis of the remaining nonmethane hydrocarbons. Each gas sampling bulb was analyzed several times to ensure a representative sample analysis.

TABLE A-3. GAS CHROMATOGRAPH SPECIFICATIONS

Varian Model 3700 Gas Chromatograph:	
Sensitivity	1×10^{-12} A/mV at attenuation 1 and range 10^{-12} A/mV
Zero range	-10^{-11} to 10^{-9} A (reversible with internal switch)
Noise (inputs capped)	5×10^{-15} A; 0.5 μV peak to peak
Time constant	220 ms on all ranges (approximate 1 sec response to 99 percent of peak)
Gas required	Carrier gas (helium), combustion air, fuel gas (hydrogen)

REFERENCES FOR APPENDIX A

A-1. Maddalone, R. and N. Gainer, "Process Measurement Procedures: H_2SO_4 Emissions", EPA-600/7-79-156, NTIS PB80-115959, July 1979.

A-2. Lentzen, D.E., et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition), EPA-600/7-78-201, NTIS PB293795, October 1978.

APPENDIX B

TRACE ELEMENT CONCENTRATIONS AND MASS BALANCES

The following tables present sample trace element analysis results and trace element discharge stream concentrations. The tables labeled "ppm" represent element analysis results (microgram per gram) for each sample analyzed. Compositions for the fuel and all SASS train samples (10 and 3 μm particulate, filter and 1 μm particulate, XAD-2 resin, first impinger, and second and third impingers) are noted. The tables labeled μg/sec, ng/Joule, and μg/dscm give calculated trace element concentrations in each of these units for the fuel and for all SASS train samples. The tables denoted as "exhaust gas" represent the appropriate sum of SASS train samples.

Symbols appearing in the tables include:

DSCM	Dry standard cubic meter at 1 atm and 20°C
MCG	Microgram
PPM	Part per million by weight
SEC	Second
ng/J	Nanogram per Joule
<	Less than
>	Greater than
N	Element not analyzed
U	Unable to determine

Trace elements having concentrations less than the detectable limit or having a blank value greater than the sample value were given an arbitrary concentration of zero. Values in the form $A < x < B$ were determined by letting elements reported as less than some concentration be represented by a concentration of zero for the low value and the reported concentration as the high value.

Detectability limits for the various SASS samples were the following:

- Filter -- <0.1 μg/g
- XAD-2 -- <0.1 μg/g
- Impinger and organic module concentrate -- <0.001 μg/ml

ADELPHI
COW + SODA ASH
MCG/SEC

MASS FLOW ELEMENT	10+3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	> .124E+03	U .000E+00	.000E+00	.291E+02	.000E+00
ANTIMONY	.783E+00	.136E+01	.000E+00	.000E+00	< .221E+01
ARSENIC	.261E+02	.847E+02	.000E+00	.000E+00	< .154E+01
BARIUM	.587E+03	.745E+03	.000E+00	.291E+01	.000E+00
BERYLLIUM	.261E+01	.984E+00	.000E+00	.000E+00	N .000E+00
BISMUTH	< .261E+00	.000E+00	.000E+00	.000E+00	N .000E+00
BORON	.939E+02	.646E+02	.536E+01	.000E+00	.000E+00
BROMINE	.274E+02	.665E+02	.000E+00	.136E+01	.000E+00
CADMIUM	.391E+00	.000E+00	.000E+00	.969E+00	N .000E+00
CALCIUM	> .130E+04	U .000E+00	.000E+00	.581E+02	.000E+00
CERIUM	.587E+02	.169E+02	.804E+01	.000E+00	N .000E+00
CESIUM	.130E+01	.203E+01	.000E+00	.388E+00	N .000E+00
CHLORINE	.704E+03	> .339E+04	.268E+02	.136E+02	.000E+00
CHROMIUM	.639E+02	.281E+03	.118E+03	.368E+02	.000E+00
COBALT	.261E+01	.674E+01	.268E+01	< .194E+00	.000E+00
COPPER	.378E+02	.406E+02	.000E+00	.957E+02	.000E+00
DYSPROSIUM	.261E+01	.000E+00	.000E+00	.000E+00	N .000E+00
ERBIUM	.117E+01	.000E+00	.000E+00	.000E+00	N .000E+00
EUROPIUM	.783E+00	.000E+00	.000E+00	.000E+00	N .000E+00
FLUORINE	.104E+02	.472E+03	.214E+02	.116E+02	.000E+00
GADOLINIUM	.391E+01	.000E+00	.000E+00	.000E+00	N .000E+00
GALLIUM	.183E+02	.237E+02	.000E+00	.194E+00	.000E+00
GERMANIUM	.130E+02	.169E+02	.000E+00	.000E+00	N .000E+00
HAFNIUM	.000E+00	.000E+00	.000E+00	.000E+00	N .000E+00
HOLMIUM	.130E+01	.000E+00	.000E+00	.000E+00	N .000E+00
IODINE	.261E+01	.132E+01	.000E+00	.000E+00	N .000E+00
IRON	> .130E+04	> .339E+04	.536E+02	> .193E+04	.000E+00
LANTHANUM	.574E+02	.135E+02	.536E+01	.000E+00	N .000E+00
LEAD	.574E+03	.576E+03	.804E+01	.128E+02	.000E+00
LITHIUM	.170E+02	.203E+02	.000E+00	.388E+01	N .000E+00
LUTETIUM	.261E+00	.000E+00	.000E+00	.000E+00	N .000E+00
MAGNESIUM	> .130E+04	.140E+04	.107E+03	.116E+03	.000E+00
MANGANESE	.417E+03	.677E+02	.107E+02	.153E+02	.000E+00
MERCURY	< .127E+02	< .125E+02	.804E+02	.969E+00	< .221E+00
MOLYBDENUM	.313E+02	.847E+02	.000E+00	.969E+01	N .000E+00
NEODYMIUM	.652E+01	.000E+00	.000E+00	.000E+00	N .000E+00
NICKEL	.129E+03	.575E+02	.241E+03	.387E+03	.000E+00
NIOBIUM	.652E+01	.339E+01	.000E+00	.775E+00	N .000E+00
PHOSPHORUS	.535E+03	.532E+03	.000E+00	.000E+00	.000E+00
PLATINUM	.000E+00	.000E+00	.134E+02	.000E+00	N .000E+00
POTASSIUM	> .130E+04	U .000E+00	.000E+00	.155E+03	.000E+00
PRASEODYMIUM	.261E+01	.169E+01	.000E+00	.000E+00	N .000E+00
RUBIDIUM	.274E+02	.677E+02	.000E+00	.775E+00	N .000E+00
SAMARIUM	.652E+01	.000E+00	.000E+00	.000E+00	N .000E+00
SCANDIUM	.783E+01	< .306E+00	.000E+00	< .194E+00	.000E+00

ADELPHI
MASS FLOW COW + SODA ASH
MCG/SEC

ELEMENT	10+3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
SELENIUM	.157E+02	.169E+02	.134E+02	.382E+02	.000E+00
SILICON	> .130E+04	U .000E+00	.000E+00	.000E+00	.000E+00
SILVER	.261E+01	.136E+01	.804E+01	.000E+00	.000E+00
SODIUM	> .313E+03	> .763E+03	.000E+00	U .000E+00	.000E+00
STRONTIUM	.887E+02	.508E+02	.000E+00	.388E+00	.000E+00
SULFUR	.143E+06	.542E+06	.134E+03	.775E+06	.000E+00
TANTALUM	.000E+00	.000E+00	.000E+00	.000E+00	N .000E+00
TELLURIUM	.391E+00	< .339E+00	.000E+00	.000E+00	N .000E+00
TERBIUM	.522E+00	.000E+00	.000E+00	.000E+00	N .000E+00
THALLIUM	.391E+01	.678E+01	.000E+00	.000E+00	N .000E+00
THORIUM	.522E+01	.000E+00	< .161E+02	< .194E+00	.000E+00
THULIUM	.391E+00	.000E+00	.000E+00	.000E+00	N .000E+00
TIN	.783E+00	.102E+01	.000E+00	.969E+00	N .000E+00
TITANIUM	.117E+04	.914E+03	.590E+02	.000E+00	.000E+00
TUNGSTEN	.117E+01	.678E+01	.000E+00	.000E+00	N .000E+00
URANIUM	.443E+02	.271E+02	< .134E+02	< .581E+00	.000E+00
VANADIUM	.626E+03	.230E+03	.000E+00	.000E+00	.000E+00
YTTERBIUM	.261E+01	.000E+00	.000E+00	.000E+00	N .000E+00
YTTRIUM	.404E+02	.101E+02	.000E+00	.000E+00	N .000E+00
ZINC	.822E+02	.878E+02	.000E+00	.180E+03	.000E+00
ZIRCONIUM	.809E+02	.100E+02	.161E+02	.194E+00	.000E+00

ADELPHI
MASS FLOW COW + SODA ASH
MCG/SEC

ELEMENT	FUEL- COW+SA	EXHAUST GAS
ALUMINUM	.485E+04	> .153E+03
ANTIMONY	.000E+00	.214E+01<X<.434E+01
ARSENIC	.000E+00	.111E+03<X<.112E+03
BARIUM	> .118E+05	.133E+04
BERYLLIUM	.237E+02	.359E+01
BISMUTH	.000E+00	< .261E+00
BORON	.118E+03	.164E+03
BROMINE	.237E+03	.952E+02
CADMIUM	.000E+00	.136E+01
CALCIUM	> .118E+05	> .136E+04
CERIUM	.130E+04	.836E+02
CESIUM	.118E+03	.372E+01
CHLORINE	.237E+03	> .413E+04
CHROMIUM	> .118E+05	.500E+03
COBALT	.118E+02	.120E+02<X<.122E+02
COPPER	.592E+03	.174E+03
DYSPROSIUM	.474E+02	.261E+01
ERBIUM	< .118E+02	.117E+01
EUROPIUM	.237E+02	.783E+00
FLUORINE	.710E+02	.516E+03
GADOLINIUM	.592E+02	.391E+01
GALLIUM	.118E+03	.421E+02
GERMANIUM	.107E+03	.300E+02
HAFNIUM	.237E+02	.000E+00
HOLMIUM	.237E+02	.130E+01
IODINE	.000E+00	.393E+01
IRON	> .118E+05	> .668E+04
LANTHANUM	.130E+04	.763E+02
LEAD	.237E+03	.117E+04
LITHIUM	.118E+02	.411E+02
LUTETIUM	.000E+00	.261E+00
MAGNESIUM	> .118E+05	> .292E+04
MANGANESE	.616E+04	.511E+03
MERCURY	.000E+00	.814E+02<X<.107E+03
MOLYBDENUM	.592E+03	.126E+03
NEODYMIUM	.237E+03	.652E+01
NICKEL	.201E+04	.815E+03
NIOBIUM	.237E+03	.107E+02
PHOSPHORUS	> .118E+05	.107E+04
PLATINUM	.000E+00	.134E+02
POTASSIUM	> .118E+05	> .146E+04
PRASEODYMIUM	.237E+03	.430E+01
RUBIDIUM	< .829E+02	.959E+02
SAMARIUM	.947E+02	.652E+01
SCANDIUM	.710E+02	783E+01<X<.833E+01

ADELPHI
COW + SODA ASH
MCG/SEC

MASS FLOW ELEMENT	FUEL- COW+SA	EXHAUST GAS
SELENIUM	.592E+03	.841E+02
SILICON	> 118E+05	> .130E+04
SILVER	000E+00	.120E+02
SODIUM	> .118E+05	> .108E+04
STRONTIUM	.343E+04	.140E+03
SULFUR	.189E+07	.146E+07
TANTALUM	.000E+00	.000E+00
TELLURIUM	.000E+00	.391E+00<X<.730E+00
TERBIUM	.237E+02	.522E+00
THALLIUM	< .237E+02	.107E+02
THORIUM	.474E+03	.522E+01<X<.215E+02
THULIUM	.000E+00	.391E+00
TIN	.000E+00	.277E+01
TITANIUM	> .118E+05	.215E+04
TUNGSTEN	.107E+03	.795E+01
URANIUM	.166E+04	.714E+02<X<.854E+02
VANADIUM	.805E+04	.856E+03
YTTERBIUM	.000E+00	.261E+01
YTTRIUM	.154E+04	.506E+02
ZINC	.355E+03	.350E+03
ZIRCONIUM	.142E+04	.107E+03

ADELPHI
COW + SODA ASH

CONCENTRATION MCG/DSCM ELEMENT	10+3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	> .982E+02	U .000E+00	.000E+00	.230E+02	.000E+00
ANTIMONY	.620E+00	.107E+01	.000E+00	.000E+00	< .175E+01
ARSENIC	.207E+02	.671E+02	.000E+00	.000E+00	< .122E+01
BARIUM	.465E+03	.590E+03	.000E+00	.230E+01	.000E+00
BERYLLIUM	.207E+01	.780E+00	.000E+00	.000E+00	N .000E+00
BISMUTH	< .207E+00	.000E+00	.000E+00	.000E+00	N .000E+00
BORON	.744E+02	.512E+02	.425E+01	.000E+00	.000E+00
BROMINE	.217E+02	.527E+02	.000E+00	.108E+01	.000E+00
CADMIUM	.310E+00	.000E+00	.000E+00	.768E+00	N .000E+00
CALCIUM	> .103E+04	U .000E+00	.000E+00	.461E+02	.000E+00
CERIUM	.465E+02	.134E+02	.638E+01	.000E+00	N .000E+00
CESIUM	.103E+01	.161E+01	.000E+00	.307E+00	N .000E+00
CHLORINE	.558E+03	> .268E+04	.213E+02	.108E+02	.000E+00
CHROMIUM	.507E+02	.223E+03	.935E+02	.292E+02	.000E+00
COBALT	.207E+01	.535E+01	.213E+01	< .154E+00	.000E+00
COPPER	.300E+02	.322E+02	.000E+00	.759E+02	.000E+00
DYSPROSIUM	.207E+01	.000E+00	.000E+00	.000E+00	N .000E+00
ERBIUM	.931E+00	.000E+00	.000E+00	.000E+00	N .000E+00
EUROPIUM	.620E+00	.000E+00	.000E+00	.000E+00	N .000E+00
FLUORINE	.827E+01	.375E+03	.170E+02	.922E+01	.000E+00
GADOLINIUM	.310E+01	.000E+00	.000E+00	.000E+00	N .000E+00
GALLIUM	.145E+02	.188E+02	.000E+00	.154E+00	.000E+00
GERMANIUM	.103E+02	.134E+02	.000E+00	.000E+00	N .000E+00
HAFNIUM	.000E+00	.000E+00	.000E+00	.000E+00	N .000E+00
HOLMIUM	.103E+01	.000E+00	.000E+00	.000E+00	N .000E+00
IODINE	.207E+01	.105E+01	.000E+00	.000E+00	N .000E+00
IRON	> .103E+04	> .268E+04	.425E+02	> .153E+04	.000E+00
LANTHANUM	.455E+02	.107E+02	.425E+01	.000E+00	N .000E+00
LEAD	.455E+03	.457E+03	.638E+01	.101E+02	.000E+00
LITHIUM	.134E+02	.161E+02	.000E+00	.307E+01	N .000E+00
LUTETIUM	.207E+00	.000E+00	.000E+00	.000E+00	N .000E+00
MAGNESIUM	> .103E+04	.111E+04	.850E+02	.922E+02	.000E+00
MANGANESE	.331E+03	.537E+02	.850E+01	.121E+02	.000E+00
MERCURY	< .100E+02	< .994E+01	.638E+02	.768E+00	< .175E+00
MOLYBDENUM	.248E+02	.672E+02	.000E+00	.768E+01	N .000E+00
NEODYMIUM	.517E+01	.000E+00	.000E+00	.000E+00	N .000E+00
NICKEL	.102E+03	.456E+02	.191E+03	.307E+03	.000E+00
NIOBIUM	.517E+01	.269E+01	.000E+00	.615E+00	N .000E+00
PHOSPHORUS	424E+03	.422E+03	.000E+00	.000E+00	.000E+00
PLATINUM	.000E+00	.000E+00	.106E+02	.000E+00	N .000E+00
POTASSIUM	> .103E+04	U .000E+00	.000E+00	.123E+03	.000E+00
PRASEODYMIUM	.207E+01	.134E+01	.000E+00	.000E+00	N .000E+00
RUBIDIUM	.217E+02	.537E+02	.000E+00	615E+00	N .000E+00
SAMARIUM	.517E+01	.000E+00	.000E+00	.000E+00	N .000E+00
SCANDIUM	.620E+01	< .243E+00	.000E+00	< .154E+00	.000E+00

ADELPHI
COW + SODA ASH

CONCENTRATION MCG/DSCM ELEMENT	10+3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
SELENIUM	.124E+02	.134E+02	.106E+02	.303E+02	.000E+00
SILICON	> .103E+04	U .000E+00	.000E+00	.000E+00	.000E+00
SILVER	.207E+01	.107E+01	.638E+01	.000E+00	.000E+00
SODIUM	> .248E+03	> .605E+03	.000E+00	U .000E+00	.000E+00
STRONTIUM	.703E+02	.402E+02	.000E+00	.307E+00	.000E+00
SULFUR	.114E+06	.430E+06	.106E+03	.614E+06	.000E+00
TANTALUM	.000E+00	.000E+00	.000E+00	.000E+00	N .000E+00
TELLURIUM	.310E+00	< .269E+00	.000E+00	.000E+00	N .000E+00
TERBIUM	.414E+00	.000E+00	.000E+00	.000E+00	N .000E+00
THALLIUM	.310E+01	.537E+01	.000E+00	.000E+00	N .000E+00
THORIUM	.414E+01	.000E+00	< .128E+02	< .154E+00	.000E+00
THULIUM	.310E+00	.000E+00	.000E+00	.000E+00	N .000E+00
TIN	.620E+00	.806E+00	.000E+00	.768E+00	N .000E+00
TITANIUM	.931E+03	.725E+03	.468E+02	.000E+00	.000E+00
TUNGSTEN	.931E+00	.537E+01	.000E+00	.000E+00	N .000E+00
URANIUM	.352E+02	.215E+02	< .106E+02	< .461E+00	.000E+00
VANADIUM	.496E+03	.183E+03	.000E+00	.000E+00	.000E+00
YTTERBIUM	.207E+01	.000E+00	000E+00	.000E+00	N .000E+00
YTTRIUM	.321E+02	.803E+01	.000E+00	.000E+00	N .000E+00
ZINC	.651E+02	.696E+02	.000E+00	.143E+03	.000E+00
ZIRCONIUM	.641E+02	.793E+01	.128E+02	.154E+00	.000E+00

CONCENTRATION	ADELPHI COW + SODA ASH MCG/DSCM
ELEMENT	EXHAUST GAS
ALUMINUM	> .121E+03
ANTIMONY	.169E+01<X<.344E+01
ARSENIC	.878E+02<X<.890E+02
BARIUM	.106E+04
BERYLLIUM	.285E+01
BISMUTH	< .207E+00
BORON	.130E+03
BROMINE	.755E+02
CADMIUM	.108E+01
CALCIUM	> .108E+04
CERIUM	.663E+02
CESIUM	.295E+01
CHLORINE	> .327E+04
CHROMIUM	.396E+03
COBALT	.954E+01<X<.969E+01
COPPER	.138E+03
DYSPROSIUM	.207E+01
ERBIUM	.931E+00
EUROPIUM	.620E+00
FLUORINE	.409E+03
GADOLINIUM	.310E+01
GALLIUM	.334E+02
GERMANIUM	.238E+02
HAFNIUM	.000E+00
HOLMIUM	.103E+01
IODINE	.312E+01
IRON	> .529E+04
LANTHANUM	.605E+02
LEAD	.928E+03
LITHIUM	.326E+02
LUTETIUM	.207E+00
MAGNESIUM	> .232E+04
MANGANESE	.405E+03
MERCURY	.645E+02<X<.847E+02
MOLYBDENUM	.997E+02
NEODYMIUM	.517E+01
NICKEL	.646E+03
NIOBIUM	.847E+01
PHOSPHORUS	.846E+03
PLATINUM	.106E+02
POTASSIUM	> .116E+04
PRASEODYMIUM	.341E+01
RUBIDIUM	.760E+02
SAMARIUM	.517E+01
SCANDIUM	.620E+01<X<.660E+01

CONCENTRATION	ADELPHI COW + SODA ASH MCG/DSCM
ELEMENT	EXHAUST GAS
SELENIUM	.667E+02
SILICON	> .103E+04
SILVER	.952E+01
SODIUM	> .853E+03
STRONTIUM	.111E+03
SULFUR	.116E+07
TANTALUM	.000E+00
TELLURIUM	.310E+00<X<.579E+00
TERBIUM	.414E+00
THALLIUM	.847E+01
THORIUM	.414E+01<X<.170E+02
THULIUM	.310E+00
TIN	.219E+01
TITANIUM	.170E+04
TUNGSTEN	.630E+01
URANIUM	.566E+02<X<.677E+02
VANADIUM	.679E+03
YTTERBIUM	.207E+01
YTTRIUM	.401E+02
ZINC	.278E+03
ZIRCONIUM	.849E+02

MASS/HEAT INPUT — ADELPHI COW + SODA ASH — NG/J

ELEMENT	10+3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	> .388E-01	U .000E+00	.000E+00	.911E-02	.000E+00
ANTIMONY	.245E-03	.425E-03	.000E+00	.000E+00	< .691E-03
ARSENIC	.818E-02	.265E-01	.000E+00	.000E+00	< .484E-03
BARIUM	.184E+00	.233E+00	.000E+00	.911E-03	.000E+00
BERYLLIUM	.818E-03	.308E-03	.000E+00	.000E+00	N .000E+00
BISMUTH	< .818E-04	.000E+00	.000E+00	.000E+00	N .000E+00
BORON	.294E-01	.203E-01	168E-02	.000E+00	.000E+00
BROMINE	.858E-02	.208E-01	.000E+00	.425E-03	.000E+00
CADMIUM	.123E-03	.000E+00	.000E+00	.304E-03	N .000E+00
CALCIUM	> .409E+00	U .000E+00	.000E+00	.182E-01	.000E+00
CERIUM	.184E-01	.530E-02	.252E-02	.000E+00	N .000E+00
CESIUM	.409E-03	.637E-03	.000E+00	.121E-03	N .000E+00
CHLORINE	.221E+00	> .106E+01	.840E-02	.425E-02	.000E+00
CHROMIUM	.200E-01	.881E-01	.370E-01	.115E-01	.000E+00
COBALT	.818E-03	.211E-02	.840E-03	< .607E-04	.000E+00
COPPER	.119E-01	.127E-01	.000E+00	.300E-01	.000E+00
DYSPROSIUM	.818E-03	.000E+00	.000E+00	.000E+00	N .000E+00
ERBIUM	.368E-03	.000E+00	.000E+00	.000E+00	N .000E+00
EUROPIUM	.245E-03	.000E+00	.000E+00	.000E+00	N .000E+00
FLUORINE	.327E-02	.148E+00	.672E-02	.364E-02	.000E+00
GADOLINIUM	.123E-02	.000E+00	.000E+00	.000E+00	N .000E+00
GALLIUM	.572E-02	.742E-02	.000E+00	.607E-04	.000E+00
GERMANIUM	.409E-02	.531E-02	.000E+00	.000E+00	N .000E+00
HAFNIUM	.000E+00	.000E+00	.000E+00	.000E+00	N .000E+00
HOLMIUM	.409E-03	.000E+00	.000E+00	.000E+00	N .000E+00
IODINE	.818E-03	.415E-03	.000E+00	.000E+00	N .000E+00
IRON	> .409E+00	> .106E+01	.168E-01	> .606E+00	.000E+00
LANTHANUM	.180E-01	.424E-02	.168E-02	.000E+00	N .000E+00
LEAD	.180E+00	.180E+00	.252E-02	.401E-02	.000E+00
LITHIUM	.531E-02	.635E-02	.000E+00	.121E-02	N .000E+00
LUTETIUM	.818E-04	.000E+00	.000E+00	.000E+00	N .000E+00
MAGNESIUM	> .409E+00	.438E+00	.336E-01	.364E-01	.000E+00
MANGANESE	.131E+00	.212E-01	.336E-02	.480E-02	.000E+00
MERCURY	< .396E-02	< .393E-02	.252E-01	.304E-03	< .691E-04
MOLYBDENUM	.981E-02	.265E-01	.000E+00	.304E-02	N .000E+00
NEODYMIUM	.204E-02	.000E+00	.000E+00	.000E+00	N .000E+00
NICKEL	.405E-01	.180E-01	.756E-01	.121E+00	.000E+00
NIOBIUM	.204E-02	.106E-02	.000E+00	.243E-03	N .000E+00
PHOSPHORUS	.168E+00	.167E+00	.000E+00	.000E+00	.000E+00
PLATINUM	.000E+00	.000E+00	.420E-02	.000E+00	N .000E+00
POTASSIUM	> .409E+00	U .000E+00	.000E+00	.486E-01	.000E+00
PRASEODYMIUM	.818E-03	.531E-03	.000E+00	.000E+00	N .000E+00
RUBIDIUM	.858E-02	.212E-01	.000E+00	.243E-03	N .000E+00
SAMARIUM	.204E-02	.000E+00	.000E+00	.000E+00	N .000E+00
SCANDIUM	.245E-02	< .960E-04	.000E+00	< 607E-04	.000E+00

ADELPHI
MASS/HEAT INPUT COW + SODA ASH
NG/J

ELEMENT	10+3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
SELENIUM	491E-02	.530E-02	.420E-02	.120E-01	.000E+00
SILICON	> .409E+00	U .000E+00	.000E+00	.000E+00	.000E+00
SILVER	.818E-03	.425E-03	.252E-02	.000E+00	.000E+00
SODIUM	> .981E-01	> .239E+00	.000E+00	U .000E+00	.000E+00
STRONTIUM	.278E-01	.159E-01	.000E+00	.121E-03	.000E+00
SULFUR	.450E+02	.170E+03	.420E-01	.243E+03	.000E+00
TANTALUM	000E+00	.000E+00	.000E+00	.000E+00	N .000E+00
TELLURIUM	.123E-03	< .106E-03	.000E+00	.000E+00	N .000E+00
TERBIUM	.164E-03	.000E+00	.000E+00	.000E+00	N .000E+00
THALLIUM	.123E-02	.212E-02	.000E+00	.000E+00	N .000E+00
THORIUM	.164E-02	.000E+00	< .504E-02	< .607E-04	.000E+00
THULIUM	.123E-03	.000E+00	.000E+00	.000E+00	N .000E+00
TIN	.245E-03	.319E-03	.000E+00	.304E-03	N .000E+00
TITANIUM	.368E+00	.287E+00	.185E-01	.000E+00	.000E+00
TUNGSTEN	.368E-03	.212E-02	.000E+00	.000E+00	N .000E+00
URANIUM	.139E-01	.848E-02	< .420E-02	< .182E-03	.000E+00
VANADIUM	.196E+00	.722E-01	.000E+00	.000E+00	.000E+00
YTTERBIUM	.818E-03	.000E+00	.000E+00	.000E+00	N .000E+00
YTTRIUM	.127E-01	.318E-02	.000E+00	.000E+00	N .000E+00
ZINC	.258E-01	.275E-01	.000E+00	.565E-01	.000E+00
ZIRCONIUM	.253E-01	.313E-02	.504E-02	.607E-04	.000E+00

MASS/HEAT INPUT	ADELPHI COW + SODA ASH NG/J	
ELEMENT	FUEL- COW+SA	EXHAUST GAS
ALUMINUM	.152E+01	> .479E-01
ANTIMONY	.000E+00	.670E-03<X<.136E-02
ARSENIC	.000E+00	.347E-01<X<.352E-01
BARIUM	> .371E+01	.418E+00
BERYLLIUM	.742E-02	.113E-02
BISMUTH	.000E+00	< .818E-04
BORON	.371E-01	.514E-01
BROMINE	.742E-01	.298E-01
CADMIUM	000E+00	.426E-03
CALCIUM	> 371E+01	> .427E+00
CERIUM	408E+00	.262E-01
CESIUM	.371E-01	.117E-02
CHLORINE	.742E-01	> .129E+01
CHROMIUM	> .371E+01	.157E+00
COBALT	.371E-02	.377E-02<X<.383E-02
COPPER	.186E+00	.546E-01
DYSPROSIUM	.148E-01	.818E-03
ERBIUM	< .371E-02	.368E-03
EUROPIUM	.742E-02	.245E-03
FLUORINE	.223E-01	.162E+00
GADOLINIUM	.186E-01	.123E-02
GALLIUM	.371E-01	.132E-01
GERMANIUM	.334E-01	.940E-02
HAFNIUM	.742E-02	.000E+00
HOLMIUM	.742E-02	.409E-03
IODINE	.000E+00	.123E-02
IRON	> .371E+01	> .209E+01
LANTHANUM	.408E+00	.239E-01
LEAD	.742E-01	.367E+00
LITHIUM	.371E-02	.129E-01
LUTETIUM	.000E+00	.818E-04
MAGNESIUM	> .371E+01	> .917E+00
MANGANESE	.193E+01	.160E+00
MERCURY	.000E+00	.255E-01<X<.335E-01
MOLYBDENUM	.186E+00	.394E-01
NEODYMIUM	.742E-01	.204E-02
NICKEL	.631E+00	.255E+00
NIOBIUM	.742E-01	.335E-02
PHOSPHORUS	> .371E+01	.334E+00
PLATINUM	.000E+00	.420E-02
POTASSIUM	> .371E+01	> .457E+00
PRASEODYMIUM	.742E-01	.135E-02
RUBIDIUM	< .260E-01	.301E-01
SAMARIUM	.297E-01	.204E-02
SCANDIUM	.223E 01	.245E-02<X<.261E-02

ADELPHI
MASS/HEAT INPUT COW + SODA ASH
NG/J

ELEMENT	FUEL- COW+SA	EXHAUST GAS
SELENIUM	.186E+00	.264E-01
SILICON	> .371E+01	> .409E+00
SILVER	.000E+00	.376E-02
SODIUM	> .371E+01	> .337E+00
STRONTIUM	.108E+01	.438E-01
SULFUR	.594E+03	.458E+03
TANTALUM	.000E+00	.000E+00
TELLURIUM	.000E+00	.123E-03<X<.229E-03
TERBIUM	.742E-02	.164E-03
THALLIUM	< .742E-02	.335E-02
THORIUM	.148E+00	.164E-02<X<.674E-02
THULIUM	.000E+00	.123E-03
TIN	.000E+00	.868E-03
TITANIUM	> .371E+01	.673E+00
TUNGSTEN	.334E-01	.249E-02
URANIUM	.519E+00	.224E-01<X<.268E-01
VANADIUM	.252E+01	.268E+00
YTTERBIUM	.000E+00	.818E-03
YTTRIUM	.482E+00	.158E-01
ZINC	.111E+00	.110E+00
ZIRCONIUM	.445E+00	.336E-01

ADELPHI
COW + SODA ASH
PPM

PPM

ELEMENT	10+3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	>.950E+02	U.000E+00	.000E+00	.150E+00	.000E+00
ANTIMONY	.600E+00	.400E+00	.000E+00	.000E+00	<.100E-01
ARSENIC	.200E+02	.250E+02	.000E+00	.000E+00	<.700E-02
BARIUM	.450E+03	.220E+03	.000E+00	.150E-01	.000E+00
BERYLLIUM	.200E+01	.290E+00	.000E+00	.000E+00	N.000E+00
BISMUTH	<.200E+00	.000E+00	.000E+00	.000E+00	N.000E+00
BORON	.720E+02	.191E+02	.200E+00	.000E+00	.000E+00
BROMINE	.210E+02	.196E+02	.000E+00	.700E-02	.000E+00
CADMIUM	.300E+00	.000E+00	.000E+00	.500E-02	N.000E+00
CALCIUM	>.100E+04	U.000E+00	.000E+00	.300E+00	.000E+00
CERIUM	.450E+02	.499E+01	.300E+00	.000E+00	N.000E+00
CESIUM	.100E+01	.600E+00	.000E+00	.200E-02	N.000E+00
CHLORINE	.540E+03	>.999E+03	.100E+01	.700E-01	.000E+00
CHROMIUM	.490E+02	.830E+02	.440E+01	.190E+00	.000E+00
COBALT	.200E+01	.199E+01	.100E+00	<.100E-02	.000E+00
COPPER	.290E+02	.120E+02	.000E+00	.494E+00	.000E+00
DYSPROSIUM	.200E+01	.000E+00	.000E+00	.000E+00	N.000E+00
ERBIUM	.900E+00	.000E+00	.000E+00	.000E+00	N.000E+00
EUROPIUM	.600E+00	.000E+00	.000E+00	.000E+00	N.000E+00
FLUORINE	.800E+01	.139E+03	.800E+00	.600E-01	.000E+00
GADOLINIUM	.300E+01	.000E+00	.000E+00	.000E+00	N.000E+00
GALLIUM	.140E+02	.699E+01	.000E+00	.100E-02	.000E+00
GERMANIUM	.100E+02	.500E+01	.000E+00	.000E+00	N.000E+00
HAFNIUM	.000E+00	.000E+00	.000E+00	.000E+00	N.000E+00
HOLMIUM	.100E+01	.000E+00	.000E+00	.000E+00	N.000E+00
IODINE	.200E+01	.390E+00	.000E+00	.000E+00	N.000E+00
IRON	>.100E+04	>.999E+03	.200E+01	>.997E+01	.000E+00
LANTHANUM	.440E+02	.399E+01	.200E+00	.000E+00	N.000E+00
LEAD	.440E+03	.170E+03	.300E+00	.660E-01	.000E+00
LITHIUM	.130E+02	.598E+01	.000E+00	.200E-01	N.000E+00
LUTETIUM	.200E+00	.000E+00	.000E+00	.000E+00	N.000E+00
MAGNESIUM	>.100E+04	.412E+03	400E+01	.600E+00	.000E+00
MANGANESE	.320E+03	.200E+02	.400E+00	.790E-01	.000E+00
MERCURY	<.970E+01	<.370E+01	.300E+01	.500E-02	<.100E-02
MOLYBDENUM	.240E+02	.250E+02	.000E+00	.500E-01	N.000E+00
NEODYMIUM	.500E+01	.000E+00	.000E+00	.000E+00	N.000E+00
NICKEL	.990E+02	.170E+02	.900E+01	.200E+01	.000E+00
NIOBIUM	.500E+01	.100E+01	.000E+00	.400E-02	N.000E+00
PHOSPHORUS	.410E+03	.157E+03	.000E+00	.000E+00	.000E+00
PLATINUM	.000E+00	.000E+00	.500E+00	.000E+00	N.000E+00
POTASSIUM	> 100E+04	U.000E+00	.000E+00	.800E+00	.000E+00
PRASEODYMIUM	200E+01	.500E+00	.000E+00	.000E+00	N.000E+00
RUBIDIUM	.210E+02	.200E+02	.000E+00	.400E-02	N.000E+00
SAMARIUM	.500E+01	.000E+00	.000E+00	.000E+00	N.000E+00
SCANDIUM	.600E+01	<.904E-01	.000E+00	<.100E-02	000E+00

ADELPHI
COW + SODA ASH
PPM

PPM ELEMENT	10+3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
SELENIUM	.120E+02	.499E+01	.500E+00	.197E+00	.000E+00
SILICON	>.100E+04	U.000E+00	.000E+00	.000E+00	.000E+00
SILVER	.200E+01	.400E+00	.300E+00	.000E+00	.000E+00
SODIUM	>.240E+03	>.225E+03	.000E+00	U.000E+00	.000E+00
STRONTIUM	.680E+02	.150E+02	.000E+00	.200E-02	.000E+00
SULFUR	.110E+06	.160E+06	.500E+01	.400E+04	.000E+00
TANTALUM	.000E+00	.000E+00	.000E+00	.000E+00	N.000E+00
TELLURIUM	.300E+00	<.100E+00	.000E+00	.000E+00	N.000E+00
TERBIUM	.400E+00	.000E+00	.000E+00	.000E+00	N.000E+00
THALLIUM	.300E+01	.200E+01	.000E+00	.000E+00	N.000E+00
THORIUM	.400E+01	.000E+00	<.600E+00	<.100E-02	.000E+00
THULIUM	.300E+00	.000E+00	.000E+00	.000E+00	N.000E+00
TIN	.600E+00	.300E+00	.000E+00	.500E-02	N.000E+00
TITANIUM	.900E+03	.270E+03	.220E+01	.000E+00	.000E+00
TUNGSTEN	.900E+00	.200E+01	.000E+00	.000E+00	N.000E+00
URANIUM	.340E+02	.799E+01	<.500E+00	<.300E-02	.000E+00
VANADIUM	.480E+03	.680E+02	.000E+00	.000E+00	.000E+00
YTTERBIUM	.200E+01	.000E+00	.000E+00	.000E+00	N.000E+00
YTTRIUM	.310E+02	.299E+01	.000E+00	.000E+00	N.000E+00
ZINC	.630E+02	.259E+02	.000E+00	.930E+00	.000E+00
ZIRCONIUM	.620E+02	.295E+01	.600E+00	.100E-02	.000E+00

PPM	ADELPHI COW + SODA ASH PPM
ELEMENT	FUEL- COW+SA
ALUMINUM	.410E+02
ANTIMONY	.000E+00
ARSENIC	.000E+00
BARIUM	>.100E+03
BERYLLIUM	.200E+00
BISMUTH	.000E+00
BORON	.100E+01
BROMINE	.200E+01
CADMIUM	.000E+00
CALCIUM	>.100E+03
CERIUM	.110E+02
CESIUM	.100E+01
CHLORINE	.200E+01
CHROMIUM	>.100E+03
COBALT	.100E+00
COPPER	.500E+01
DYSPROSIUM	.400E+00
ERBIUM	<.100E+00
EUROPIUM	.200E+00
FLUORINE	.600E+00
GADOLINIUM	.500E+00
GALLIUM	.100E+01
GERMANIUM	.900E+00
HAFNIUM	.200E+00
HOLMIUM	.200E+00
IODINE	.000E+00
IRON	>.100E+03
LANTHANUM	.110E+02
LEAD	.200E+01
LITHIUM	.100E+00
LUTETIUM	.000E+00
MAGNESIUM	>.100E+03
MANGANESE	.520E+02
MERCURY	.000E+00
MOLYBDENUM	.500E+01
NEODYMIUM	.200E+01
NICKEL	.170E+02
NIOBIUM	.200E+01
PHOSPHORUS	>.100E+03
PLATINUM	.000E+00
POTASSIUM	>.100E+03
PRASEODYMIUM	.200E+01
RUBIDIUM	<.700E+00
SAMARIUM	.800E+00
SCANDIUM	.600E+00

PPM	ADELPHI COW + SODA ASH PPM
ELEMENT	FUEL- COW+SA
SELENIUM	.500E+01
SILICON	>.100E+03
SILVER	.000E+00
SODIUM	>.100E+03
STRONTIUM	.290E+02
SULFUR	160E+05
TANTALUM	.000E+00
TELLURIUM	.000E+00
TERBIUM	.200E+00
THALLIUM	<.200E+00
THORIUM	.400E+01
THULIUM	.000E+00
TIN	.000E+00
TITANIUM	>.100E+03
TUNGSTEN	.900E+00
URANIUM	.140E+02
VANADIUM	.680E+02
YTTERBIUM	.000E+00
YTTRIUM	.130E+02
ZINC	.300E+01
ZIRCONIUM	.120E+02

ADELPHI
COAL-OIL-WATER

MASS FLOW MCG/SEC

ELEMENT	10 + 3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	> .173E+03	U .000E+00	.227E+02	.155E+02	.000E+00
ANTIMONY	.133E+01	.495E+01	.000E+00	.415E+00	< .972E+00
ARSENIC	.915E+02	.132E+03	.000E+00	.000E+00	< .681E+00
BARIUM	.819E+03	> .825E+03	.000E+00	.155E+01	.000E+00
BERYLLIUM	.381E+01	.132E+02	.000E+00	.000E+00	N .000E+00
BISMUTH	.133E+01	.577E+00	.000E+00	.000E+00	N .000E+00
BORON	.400E+02	.732E+02	.757E+00	.000E+00	.000E+00
BROMINE	.381E+02	.137E+02	.151E+02	< .518E+00	.000E+00
CADMIUM	.133E+01	.247E+00	.000E+00	< .104E+00	N .000E+00
CALCIUM	> .191E+04	U .000E+00	.553E+03	.415E+02	.000E+00
CERIUM	.101E+03	.990E+02	.303E+01	< .104E+00	N .000E+00
CESIUM	.572E+01	.495E+01	.000E+00	< .104E+00	N .000E+00
CHLORINE	.972E+02	.189E+02	.908E+02	.104E+01	.000E+00
CHROMIUM	.191E+03	.231E+03	.106E+02	> .104E+04	.000E+00
COBALT	.133E+02	.272E+02	.000E+00	.104E+00	.000E+00
COPPER	.591E+02	.478E+02	.757E+01	.616E+02	.000E+00
DYSPROSIUM	.762E+01	.660E+01	.000E+00	.000E+00	N .000E+00
ERBIUM	.381E+01	.330E+01	.000E+00	.000E+00	N .000E+00
EUROPIUM	.381E+01	.165E+01	.000E+00	.000E+00	N .000E+00
FLUORINE	.267E+02	.123E+03	.212E+02	.166E+02	.000E+00
GADOLINIUM	.953E+01	.412E+01	.000E+00	.000E+00	N .000E+00
GALLIUM	.572E+02	.528E+02	.378E+01	.311E+00	.000E+00
GERMANIUM	.172E+02	.396E+02	.000E+00	.104E+00	N .000E+00
HAFNIUM	.191E+01	.165E+01	.000E+00	.000E+00	N .000E+00
HOLMIUM	.572E+01	.412E+01	.000E+00	.000E+00	N .000E+00
IODINE	.381E+01	.164E+01	.000E+00	< .104E+00	N .000E+00
IRON	> .191E+04	> .824E+03	.227E+02	> .103E+04	.000E+00
LANTHANUM	.800E+02	.825E+02	.227E+01	< .104E+00	N .000E+00
LEAD	.800E+03	.190E+03	.606E+01	.825E+02	.000E+00
LITHIUM	.248E+02	.115E+03	.757E+00	.622E+01	N .000E+00
LUTETIUM	.381E+00	.412E+00	.000E+00	.000E+00	N .000E+00
MAGNESIUM	> .191E+04	> .817E+03	.227E+02	.000E+00	.000E+00
MANGANESE	.591E+03	> .825E+03	.606E+01	.517E+02	.000E+00
MERCURY	.152E-01	.388E+00	< .530E-02	.176E+00	.681E-01
MOLYBDENUM	.191E+02	.223E+02	.378E+02	.207E+02	N .000E+00
NEODYMIUM	.476E+02	.223E+02	.000E+00	.000E+00	N .000E+00
NICKEL	.724E+02	.330E+03	.000E+00	> .104E+04	.000E+00
NIOBIUM	.229E+02	.181E+02	.000E+00	.000E+00	N .000E+00
PHOSPHORUS	> .191E+04	> .822E+03	.000E+00	.000E+00	000E+00
PLATINUM	.000E+00	.000E+00	.227E+01	.000E+00	N .000E+00
POTASSIUM	> .191E+04	U .000E+00	.136E+03	.518E+02	.000E+00
PRASEODYMIUM	.229E+02	.181E+02	.000E+00	.000E+00	N .000E+00
RUBIDIUM	.667E+02	.684E+02	< .757E+00	< .104E+00	N .000E+00
SAMARIUM	.362E+02	.165E+02	.000E+00	.000E+00	N .000E+00
SCANDIUM	101E+03	.462E+02	.000E+00	.000E+00	000E+00

ADELPHI
COAL-OIL-WATER

MASS FLOW MCG/SEC ELEMENT	10 + 3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
SELENIUM	.210E+03	.989E+01	.000E+00	< .725E+00	.000E+00
SILICON	> .191E+04	U .000E+00	.000E+00	.104E+02	.000E+00
SILVER	< .381E+00	.825E+00	.000E+00	.000E+00	.000E+00
SODIUM	> .438E+03	> .202E+03	.454E+03	U .000E+00	.000E+00
STRONTIUM	.381E+03	.322E+03	.681E+01	.207E+00	.000E+00
SULFUR	.210E+05	> .495E+03	.151E+03	.135E+07	.000E+00
TANTALUM	.572E+00	.660E+00	.000E+00	.000E+00	N .000E+00
TELLURIUM	.572E+00	.000E+00	.000E+00	< .104E+00	N .000E+00
TERBIUM	.381E+01	.825E+00	.000E+00	.000E+00	N .000E+00
THALLIUM	.191E+02	.825E+01	.000E+00	.000E+00	N .000E+00
THORIUM	.324E+02	.148E+02	< .227E+01	.000E+00	.000E+00
THULIUM	.572E+00	.660E+00	.000E+00	.000E+00	N .000E+00
TIN	.114E+01	.330E+01	.000E+00	415E+00	N .000E+00
TITANIUM	> .191E+04	> .825E+03	.757E+00	.487E+01	.000E+00
TUNGSTEN	.381E+01	.412E+01	.000E+00	.000E+00	N .000E+00
URANIUM	.152E+03	.561E+02	< .151E+01	.000E+00	.000E+00
VANADIUM	.877E+03	.396E+03	.000E+00	.829E+00	.000E+00
YTTERBIUM	.381E+01	.495E+01	.000E+00	.000E+00	N .000E+00
YTTRIUM	.572E+02	.115E+03	.000E+00	< .104E+00	N .000E+00
ZINC	.286E+03	.132E+03	.000E+00	> .103E+04	.000E+00
ZIRCONIUM	.286E+03	.511E+02	.303E+01	.518E+00	.000E+00

ADELPHI
COAL-OIL-WATER

MASS FLOW MCG/SEC

ELEMENT	FUEL-COW	EXHAUST GAS
ALUMINUM	> .240E+04	> .212E+03
ANTIMONY	.000E+00	.670E+01<X<.767E+01
ARSENIC	.480E+03	.224E+03
BARIUM	.264E+04	> .165E+04
BERYLLIUM	.360E+02	.170E+02
BISMUTH	.000E+00	.191E+01
BORON	.240E+03	.114E+03
BROMINE	.840E+02	.674E+02
CADMIUM	480E+01	.158E+01<X<.168E+01
CALCIUM	> 120E+05	> .250E+04
CERIUM	.120E+03	.203E+03
CESIUM	.360E+02	.108E+02
CHLORINE	120E+03	.208E+03
CHROMIUM	.720E+03	> .147E+04
COBALT	.240E+03	.406E+02
COPPER	.360E+03	.176E+03
DYSPROSIUM	.000E+00	.142E+02
ERBIUM	.000E+00	.711E+01
EUROPIUM	.600E+01	.546E+01
FLUORINE	.840E+03	.188E+03
GADOLINIUM	.000E+00	.137E+02
GALLIUM	.120E+03	.114E+03
GERMANIUM	.720E+02	.568E+02
HAFNIUM	.000E+00	.355E+01
HOLMIUM	.000E+00	.984E+01
IODINE	.480E+02	.545E+01<X<.555E+01
IRON	> .120E+05	> .379E+04
LANTHANUM	.240E+03	.165E+03
LEAD	.480E+03	.108E+04
LITHIUM	.120E+03	.147E+03
LUTETIUM	.000E+00	.793E+00
MAGNESIUM	.110E+05	> .275E+04
MANGANESE	.120E+04	> .147E+04
MERCURY	.000E+00	.652E+00
MOLYBDENUM	.120E+03	.999E+02
NEODYMIUM	.720E+02	.699E+02
NICKEL	.960E+03	> .144E+04
NIOBIUM	.600E+02	.410E+02
PHOSPHORUS	.420E+04	> .273E+04
PLATINUM	.000E+00	.227E+01
POTASSIUM	> .120E+05	> .209E+04
PRASEODYMIUM	.360E+02	.410E+02
RUBIDIUM	.240E+03	.136E+03
SAMARIUM	.480E+02	.527E+02
SCANDIUM	.360E+02	.147E+03

ADELPHI
MASS FLOW COAL-OIL-WATER
MCG/SEC

ELEMENT	FUEL-COW	EXHAUST GAS
SELENIUM	.360E+03	.220E+03
SILICON	> .120E+05	> .192E+04
SILVER	.960E+01	.825E+00<X<.121E+01
SODIUM	> .612E+04	> .109E+04
STRONTIUM	.960E+03	.710E+03
SULFUR	.192E+07	> .137E+07
TANTALUM	.000E+00	.123E+01
TELLURIUM	.000E+00	.572E+00<X<.675E+00
TERBIUM	.000E+00	.464E+01
THALLIUM	.480E+02	.273E+02
THORIUM	.480E+02	.472E+02<X<.495E+02
THULIUM	.000E+00	.123E+01
TIN	.600E+01	.486E+01
TITANIUM	> .120E+05	> .274E+04
TUNGSTEN	.000E+00	.793E+01
URANIUM	.840E+02	.210E+03
VANADIUM	.180E+04	.127E+04
YTTERBIUM	.000E+00	.876E+01
YTTRIUM	.360E+03	.173E+03
ZINC	.720E+03	> .145E+04
ZIRCONIUM	.720E+02	.340E+03

ADELPHI
COAL-OIL-WATER

CONCENTRATION MCG/DSCM ELEMENT	10 + 3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	> .125E+03	U .000E+00	.164E+02	.112E+02	.000E+00
ANTIMONY	.964E+00	.357E+01	.000E+00	.299E+00	< .702E+00
ARSENIC	.661E+02	.953E+02	.000E+00	.000E+00	< .492E+00
BARIUM	.592E+03	> .596E+03	.000E+00	.112E+01	.000E+00
BERYLLIUM	.275E+01	.953E+01	.000E+00	.000E+00	N .000E+00
BISMUTH	.964E+00	.417E+00	.000E+00	.000E+00	N .000E+00
BORON	.289E+02	.529E+02	.547E+00	.000E+00	.000E+00
BROMINE	.275E+02	.986E+01	.109E+02	< .374E+00	.000E+00
CADMIUM	.964E+00	.179E+00	.000E+00	< .749E-01	N .000E+00
CALCIUM	> .138E+04	U .000E+00	.399E+03	.299E+02	.000E+00
CERIUM	.730E+02	.715E+02	.219E+01	< .749E-01	N .000E+00
CESIUM	.413E+01	.357E+01	.000E+00	< .749E-01	N .000E+00
CHLORINE	.702E+02	.136E+02	.656E+02	.749E+00	.000E+00
CHROMIUM	.138E+03	.167E+03	.765E+01	> .748E+03	.000E+00
COBALT	.964E+01	.197E+02	.000E+00	.749E-01	.000E+00
COPPER	.427E+02	.345E+02	.547E+01	.445E+02	.000E+00
DYSPROSIUM	.551E+01	.477E+01	.000E+00	.000E+00	N .000E+00
ERBIUM	.275E+01	.238E+01	.000E+00	.000E+00	N .000E+00
EUROPIUM	.275E+01	.119E+01	.000E+00	.000E+00	N .000E+00
FLUORINE	.193E+02	.890E+02	.153E+02	.120E+02	.000E+00
GADOLINIUM	.688E+01	.298E+01	.000E+00	.000E+00	N .000E+00
GALLIUM	.413E+02	.381E+02	.273E+01	.225E+00	.000E+00
GERMANIUM	.124E+02	.286E+02	.000E+00	.749E-01	N .000E+00
HAFNIUM	.138E+01	.119E+01	.000E+00	.000E+00	N .000E+00
HOLMIUM	.413E+01	.298E+01	.000E+00	.000E+00	N .000E+00
IODINE	.275E+01	.118E+01	.000E+00	< .749E-01	N .000E+00
IRON	> .138E+04	> .595E+03	.164E+02	> .746E+03	.000E+00
LANTHANUM	.578E+02	.596E+02	.164E+01	< .749E-01	N .000E+00
LEAD	.578E+03	.137E+03	.437E+01	.596E+02	.000E+00
LITHIUM	.179E+02	.834E+02	.547E+00	.449E+01	N .000E+00
LUTETIUM	.275E+00	.298E+00	.000E+00	.000E+00	N .000E+00
MAGNESIUM	> 138E+04	> .590E+03	.164E+02	.000E+00	.000E+00
MANGANESE	.427E+03	> .596E+03	.437E+01	.374E+02	.000E+00
MERCURY	110E-01	.280E+00	< .383E-02	.127E+00	.492E-01
MOLYBDENUM	.138E+02	.161E+02	.273E+02	.150E+02	N .000E+00
NEODYMIUM	.344E+02	.161E+02	.000E+00	.000E+00	N .000E+00
NICKEL	.523E+02	.238E+03	.000E+00	> .748E+03	.000E+00
NIOBIUM	.165E+02	.131E+02	.000E+00	.000E+00	N .000E+00
PHOSPHORUS	> .138E+04	> .594E+03	.000E+00	.000E+00	.000E+00
PLATINUM	.000E+00	.000E+00	.164E+01	.000E+00	N .000E+00
POTASSIUM	> 138E+04	U .000E+00	.984E+02	.374E+02	.000E+00
PRASEODYMIUM	.165E+02	.131E+02	.000E+00	.000E+00	N .000E+00
RUBIDIUM	.482E+02	.494E+02	< .547E+00	< .749E-01	N .000E+00
SAMARIUM	.262E+02	.119E+02	.000E+00	.000E+00	N .000E+00
SCANDIUM	730E+02	334E+02	000E+00	.000E+00	.000E+00

ADELPHI
COAL-OIL-WATER

CONCENTRATION MCG/DSCM

ELEMENT	10 + 3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
SELENIUM	.151E+03	.714E+01	.000E+00	< .524E+00	.000E+00
SILICON	> .138E+04	U .000E+00	.000E+00	.749E+01	.000E+00
SILVER	< .275E+00	.596E+00	.000E+00	.000E+00	.000E+00
SODIUM	> .317E+03	> .146E+03	.328E+03	U .000E+00	.000E+00
STRONTIUM	.275E+03	.232E+03	.492E+01	.150E+00	.000E+00
SULFUR	.151E+05	> .357E+03	.109E+03	.973E+06	.000E+00
TANTALUM	.413E+00	.477E+00	.000E+00	.000E+00	N .000E+00
TELLURIUM	.413E+00	.000E+00	.000E+00	< .749E-01	N .000E+00
TERBIUM	.275E+01	.596E+00	.000E+00	.000E+00	N .000E+00
THALLIUM	.138E+02	.596E+01	.000E+00	.000E+00	N .000E+00
THORIUM	.234E+02	.107E+02	< .164E+01	.000E+00	.000E+00
THULIUM	.413E+00	.477E+00	.000E+00	.000E+00	N .000E+00
TIN	.826E+00	.238E+01	.000E+00	.299E+00	N .000E+00
TITANIUM	> .138E+04	> .596E+03	.547E+00	.352E+01	.000E+00
TUNGSTEN	.275E+01	.298E+01	.000E+00	.000E+00	N .000E+00
URANIUM	.110E+03	.405E+02	< .109E+01	.000E+00	.000E+00
VANADIUM	.633E+03	.286E+03	.000E+00	.599E+00	.000E+00
YTTERBIUM	.275E+01	.357E+01	.000E+00	.000E+00	N .000E+00
YTTRIUM	.413E+02	.834E+02	.000E+00	< .749E-01	N .000E+00
ZINC	.206E+03	.953E+02	.000E+00	> .743E+03	.000E+00
ZIRCONIUM	.206E+03	.369E+02	.219E+01	.374E+00	.000E+00

CONCENTRATION	ADELPHI COAL-OIL-WATER MCG/DSCM
ELEMENT	EXHAUST GAS
ALUMINUM	> .153E+03
ANTIMONY	484E+01<X<.554E+01
ARSENIC	.162E+03
BARIUM	> .119E+04
BERYLLIUM	.123E+02
BISMUTH	.138E+01
BORON	.823E+02
BROMINE	.487E+02
CADMIUM	.114E+01<X<.122E+01
CALCIUM	> .181E+04
CERIUM	.147E+03
CESIUM	.778E+01
CHLORINE	.150E+03
CHROMIUM	> .106E+04
COBALT	.294E+02
COPPER	.127E+03
DYSPROSIUM	.103E+02
ERBIUM	.514E+01
EUROPIUM	.394E+01
FLUORINE	.136E+03
GADOLINIUM	.986E+01
GALLIUM	.824E+02
GERMANIUM	.411E+02
HAFNIUM	.257E+01
HOLMIUM	.711E+01
IODINE	.394E+01<X<.401E+01
IRON	> .273E+04
LANTHANUM	.119E+03
LEAD	.779E+03
LITHIUM	.106E+03
LUTETIUM	.573E+00
MAGNESIUM	> .198E+04
MANGANESE	> .106E+04
MERCURY	.471E+00
MOLYBDENUM	.722E+02
NEODYMIUM	.505E+02
NICKEL	> .104E+04
NIOBIUM	.296E+02
PHOSPHORUS	> .197E+04
PLATINUM	.164E+01
POTASSIUM	> .151E+04
PRASEODYMIUM	.296E+02
RUBIDIUM	.982E+02
SAMARIUM	.381E+02
SCANDIUM	.106E+03

CONCENTRATION	ADELPHI COAL-OIL-WATER MCG/DSCM
ELEMENT	EXHAUST GAS
SELENIUM	.159E+03
SILICON	> .138E+04
SILVER	.596E+00<X<.871E+00
SODIUM	> .790E+03
STRONTIUM	.513E+03
SULFUR	> .989E+06
TANTALUM	.890E+00
TELLURIUM	.413E+00<X<.488E+00
TERBIUM	.335E+01
THALLIUM	.197E+02
THORIUM	.341E+02<X<.358E+02
THULIUM	.890E+00
TIN	.351E+01
TITANIUM	> .198E+04
TUNGSTEN	.573E+01
URANIUM	.152E+03
VANADIUM	.920E+03
YTTERBIUM	.633E+01
YTTRIUM	.125E+03
ZINC	> .105E+04
ZIRCONIUM	.246E+03

ADELPHI
COAL-OIL-WATER

MASS/HEAT INPUT NG/J

ELEMENT	10 + 3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	> .460E-01	U .000E+00	.603E-02	.412E-02	.000E+00
ANTIMONY	.354E-03	.131E-02	.000E+00	.110E-03	< .258E-03
ARSENIC	.243E-01	.350E-01	.000E+00	.000E+00	< .181E-03
BARIUM	.217E+00	> .219E+00	.000E+00	.412E-03	.000E+00
BERYLLIUM	.101E-02	.350E-02	.000E+00	.000E+00	N .000E+00
BISMUTH	.354E-03	.153E-03	.000E+00	.000E+00	N .000E+00
BORON	106E-01	.194E-01	.201E-03	.000E+00	.000E+00
BROMINE	.101E-01	.362E-02	.402E-02	< .137E-03	.000E+00
CADMIUM	.354E-03	.656E-04	.000E+00	< .275E-04	N .000E+00
CALCIUM	> .506E+00	U .000E+00	.147E+00	.110E-01	.000E+00
CERIUM	.268E-01	.263E-01	.803E-03	< .275E-04	N .000E+00
CESIUM	.152E-02	.131E-02	.000E+00	< .275E-04	N .000E+00
CHLORINE	.258E-01	.501E-02	.241E-01	.275E-03	.000E+00
CHROMIUM	.506E-01	.613E-01	.281E-02	> .275E+00	.000E+00
COBALT	.354E-02	.722E-02	.000E+00	.275E-04	.000E+00
COPPER	.157E-01	.127E-01	.201E-02	.163E-01	.000E+00
DYSPROSIUM	.202E-02	.175E-02	.000E+00	.000E+00	N .000E+00
ERBIUM	.101E-02	.875E-03	.000E+00	.000E+00	N .000E+00
EUROPIUM	.101E-02	.438E-03	.000E+00	.000E+00	N .000E+00
FLUORINE	.708E-02	.327E-01	.562E-02	.440E-02	.000E+00
GADOLINIUM	.253E-02	.109E-02	.000E+00	.000E+00	N .000E+00
GALLIUM	.152E-01	.140E-01	.100E-02	.825E-04	.000E+00
GERMANIUM	.455E-02	.105E-01	.000E+00	.275E-04	N .000E+00
HAFNIUM	.506E-03	.438E-03	.000E+00	.000E+00	N .000E+00
HOLMIUM	.152E-02	.109E-02	.000E+00	.000E+00	N .000E+00
IODINE	.101E-02	.435E-03	.000E+00	< .275E-04	N .000E+00
IRON	> .506E+00	> .219E+00	.603E-02	> .274E+00	.000E+00
LANTHANUM	.212E-01	.219E-01	.603E-03	< .275E-04	N .000E+00
LEAD	.212E+00	.503E-01	.161E-02	.219E-01	.000E+00
LITHIUM	.657E-02	.306E-01	.201E-03	.165E-02	N .000E+00
LUTETIUM	.101E-03	.109E-03	.000E+00	.000E+00	N .000E+00
MAGNESIUM	> .506E+00	> .217E+00	.603E-02	.000E+00	.000E+00
MANGANESE	.157E+00	> .219E+00	.161E-02	.137E-01	.000E+00
MERCURY	.405E-05	.103E-03	< .141E-05	.467E-04	.181E-04
MOLYBDENUM	.506E-02	.591E-02	.100E-01	.550E-02	N .000E+00
NEODYMIUM	.126E-01	.591E-02	.000E+00	.000E+00	N .000E+00
NICKEL	.192E-01	.875E-01	.000E+00	> .275E+00	.000E+00
NIOBIUM	.607E-02	.481E-02	.000E+00	.000E+00	N .000E+00
PHOSPHORUS	> .506E+00	> .218E+00	.000E+00	.000E+00	.000E+00
PLATINUM	.000E+00	.000E+00	.603E-03	.000E+00	N .000E+00
POTASSIUM	> .506E+00	U .000E+00	.362E-01	.137E-01	.000E+00
PRASEODYMIUM	.607E-02	.481E-02	.000E+00	.000E+00	N .000E+00
RUBIDIUM	.177E-01	.182E-01	< .201E-03	< .275E-04	N .000E+00
SAMARIUM	.961E-02	.438E-02	.000E+00	.000E+00	N .000E+00
SCANDIUM	.268E-01	.123E-01	.000E+00	.000E+00	.000E+00

ADELPHI
MASS/HEAT INPUT COAL-OIL-WATER
NG/J

ELEMENT	10 + 3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
SELENIUM	.556E-01	.262E-02	.000E+00	< .192E-03	.000E+00
SILICON	> .506E+00	U .000E+00	.000E+00	.275E-02	.000E+00
SILVER	< .101E-03	.219E-03	.000E+00	.000E+00	.000E+00
SODIUM	> .116E+00	> .535E-01	.121E+00	U .000E+00	.000E+00
STRONTIUM	.101E+00	.853E-01	.181E-02	.550E-04	.000E+00
SULFUR	.556E+01	> .131E+00	.402E-01	.357E+03	.000E+00
TANTALUM	.152E-03	.175E-03	.000E+00	.000E+00	N .000E+00
TELLURIUM	.152E-03	.000E+00	.000E+00	< .275E-04	N .000E+00
TERBIUM	.101E-02	.219E-03	.000E+00	.000E+00	N .000E+00
THALLIUM	.506E-02	.219E-02	.000E+00	.000E+00	N .000E+00
THORIUM	.860E-02	.393E-02	< .603E-03	.000E+00	.000E+00
THULIUM	.152E-03	.175E-03	.000E+00	.000E+00	N .000E+00
TIN	.303E-03	.875E-03	.000E+00	.110E-03	N .000E+00
TITANIUM	> .506E+00	> .219E+00	.201E-03	.129E-02	.000E+00
TUNGSTEN	.101E-02	.109E-02	.000E+00	.000E+00	N .000E+00
URANIUM	.405E-01	.149E-01	< .402E-03	.000E+00	.000E+00
VANADIUM	.233E+00	.105E+00	.000E+00	.220E-03	.000E+00
YTTERBIUM	.101E-02	.131E-02	.000E+00	.000E+00	N .000E+00
YTTRIUM	.152E-01	.306E-01	.000E+00	< .275E-04	N .000E+00
ZINC	.758E-01	.350E-01	.000E+00	> .273E+00	.000E+00
ZIRCONIUM	.758E-01	.136E-01	.803E-03	.137E-03	.000E+00

ADELPHI
MASS/HEAT INPUT COAL-OIL-WATER
NG/J

ELEMENT	FUEL-COW	EXHAUST GAS
ALUMINUM	> .637E+00	> .562E-01
ANTIMONY	.000E+00	178E-02<X<.203E-02
ARSENIC	.127E+00	.595E-01
BARIUM	.700E+00	> .437E+00
BERYLLIUM	.955E-02	.451E-02
BISMUTH	.000E+00	.507E-03
BORON	.637E-01	.302E-01
BROMINE	.223E-01	.179E-01
CADMIUM	.127E-02	.420E-03<X<.447E-03
CALCIUM	> .318E+01	> .663E+00
CERIUM	.318E-01	.539E-01
CESIUM	.955E-02	.286E-02
CHLORINE	.318E-01	.552E-01
CHROMIUM	.191E+00	> .389E+00
COBALT	.637E-01	.108E-01
COPPER	.955E-01	.467E-01
DYSPROSIUM	.000E+00	.377E-02
ERBIUM	.000E+00	.189E-02
EUROPIUM	.159E-02	.145E-02
FLUORINE	.223E+00	.498E-01
GADOLINIUM	.000E+00	.362E-02
GALLIUM	.318E-01	.303E-01
GERMANIUM	.191E-01	.151E-01
HAFNIUM	.000E+00	.943E-03
HOLMIUM	.000E+00	.261E-02
IODINE	.127E-01	.145E-02<X<.147E-02
IRON	> .318E+01	> .100E+01
LANTHANUM	.637E-01	.437E-01
LEAD	.127E+00	.286E+00
LITHIUM	.318E-01	.391E-01
LUTETIUM	.000E+00	.211E-03
MAGNESIUM	.293E+01	> .729E+00
MANGANESE	.318E+00	> .391E+00
MERCURY	.000E+00	.173E-03
MOLYBDENUM	.318E-01	.265E-01
NEODYMIUM	.191E-01	.185E-01
NICKEL	.255E+00	> .382E+00
NIOBIUM	.159E-01	.109E-01
PHOSPHORUS	111E+01	> .724E+00
PLATINUM	.000E+00	.603E-03
POTASSIUM	> .318E+01	> .556E+00
PRASEODYMIUM	.955E-02	.109E-01
RUBIDIUM	.637E-01	361E-01
SAMARIUM	.127E-01	.140E-01
SCANDIUM	.955E-02	.390E-01

ADELPHI
COAL-OIL-WATER

MASS/HEAT INPUT NG/J

ELEMENT	FUEL-COW	EXHAUST GAS
SELENIUM	.955E-01	.584E-01
SILICON	> .318E+01	> .508E+00
SILVER	.255E-02	.219E-03<X<.320E-03
SODIUM	> .162E+01	> .290E+00
STRONTIUM	.255E+00	.188E+00
SULFUR	.509E+03	> .363E+03
TANTALUM	.000E+00	.327E-03
TELLURIUM	.000E+00	.152E-03<X<.179E-03
TERBIUM	.000E+00	.123E-02
THALLIUM	.127E-01	.724E-02
THORIUM	.127E-01	.125E-01<X<.131E-01
THULIUM	.000E+00	.327E-03
TIN	.159E-02	.129E-02
TITANIUM	> .318E+01	> .726E+00
TUNGSTEN	.000E+00	.211E-02
URANIUM	.223E-01	.557E-01
VANADIUM	.477E+00	.338E+00
YTTERBIUM	.000E+00	.232E-02
YTTRIUM	.955E-01	.458E-01
ZINC	.191E+00	> .384E+00
ZIRCONIUM	.191E-01	.903E-01

ADELPHI
COAL-OIL-WATER
PPM

PPM ELEMENT	10 + 3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	>.910E+02	U.000E+00	.300E+01	.150E+00	.000E+00
ANTIMONY	.700E+00	.600E+01	.000E+00	.400E-02	<.100E-01
ARSENIC	.480E+02	.160E+03	.000E+00	.000E+00	<.700E-02
BARIUM	.430E+03	>.100E+04	.000E+00	.150E-01	.000E+00
BERYLLIUM	.200E+01	.160E+02	000E+00	.000E+00	N.000E+00
BISMUTH	.700E+00	.700E+00	.000E+00	.000E+00	N.000E+00
BORON	.210E+02	.888E+02	.100E+00	.000E+00	.000E+00
BROMINE	.200E+02	.166E+02	.200E+01	<.500E-02	.000E+00
CADMIUM	.700E+00	.300E+00	.000E+00	<.100E-02	N.000E+00
CALCIUM	>.100E+04	U.000E+00	.730E+02	.400E+00	.000E+00
CERIUM	.530E+02	.120E+03	.400E+00	<.100E-02	N.000E+00
CESIUM	.300E+01	.600E+01	.000E+00	<.100E-02	N.000E+00
CHLORINE	.510E+02	.229E+02	.120E+02	.100E-01	.000E+00
CHROMIUM	.100E+03	.280E+03	.140E+01	>.999E+01	.000E+00
COBALT	.700E+01	.330E+02	.000E+00	.100E-02	.000E+00
COPPER	.310E+02	.580E+02	.100E+01	.594E+00	.000E+00
DYSPROSIUM	.400E+01	.800E+01	.000E+00	.000E+00	N.000E+00
ERBIUM	.200E+01	.400E+01	.000E+00	.000E+00	N.000E+00
EUROPIUM	.200E+01	.200E+01	.000E+00	.000E+00	N.000E+00
FLUORINE	.140E+02	.149E+03	.280E+01	.160E+00	.000E+00
GADOLINIUM	.500E+01	.500E+01	.000E+00	.000E+00	N.000E+00
GALLIUM	.300E+02	.640E+02	.500E+00	.300E-02	.000E+00
GERMANIUM	.900E+01	.480E+02	.000E+00	.100E-02	N.000E+00
HAFNIUM	.100E+01	.200E+01	.000E+00	.000E+00	N.000E+00
HOLMIUM	.300E+01	.500E+01	.000E+00	.000E+00	N.000E+00
IODINE	.200E+01	.199E+01	.000E+00	<.100E-02	N.000E+00
IRON	>.100E+04	>.999E+03	.300E+01	>.997E+01	.000E+00
LANTHANUM	.420E+02	.100E+03	.300E+00	<.100E-02	N.000E+00
LEAD	.420E+03	.230E+03	.800E+00	.796E+00	.000E+00
LITHIUM	.130E+02	.140E+03	.100E+00	.600E-01	N.000E+00
LUTETIUM	.200E+00	.500E+00	.000E+00	.000E+00	N.000E+00
MAGNESIUM	>.100E+04	>.991E+03	.300E+01	.000E+00	.000E+00
MANGANESE	.310E+03	>.100E+04	.800E+00	.499E+00	.000E+00
MERCURY	.800E-02	.470E+00	<.700E-03	.170E-02	.700E-03
MOLYBDENUM	.100E+02	.270E+02	.500E+01	.200E+00	N.000E+00
NEODYMIUM	.250E+02	.270E+02	.000E+00	.000E+00	N.000E+00
NICKEL	.380E+02	.400E+03	.000E+00	>.100E+02	.000E+00
NIOBIUM	.120E+02	.220E+02	.000E+00	.000E+00	N.000E+00
PHOSPHORUS	>.100E+04	>.997E+03	.000E+00	.000E+00	.000E+00
PLATINUM	.000E+00	.000E+00	.300E+00	.000E+00	N.000E+00
POTASSIUM	>.100E+04	U.000E+00	.180E+02	.500E+00	.000E+00
PRASEODYMIUM	.120E+02	.220E+02	.000E+00	.000E+00	N.000E+00
RUBIDIUM	.350E+02	.830E+02	<.100E+00	<.100E-02	N.000E+00
SAMARIUM	.190E+02	.200E+02	.000E+00	.000E+00	N.000E+00
SCANDIUM	.530E+02	.560E+02	.000E+00	.000E+00	.000E+00

ADELPHI
PPM COAL-OIL-WATER
PPM

ELEMENT	10 + 3 MICRON	1 MICRON + FILTER	XAD-2	1ST IMPINGER	2ND & 3RD IMPINGERS
SELENIUM	.110E+03	.120E+02	.000E+00	<.700E-02	.000E+00
SILICON	>.100E+04	U.000E+00	.000E+00	.100E+00	.000E+00
SILVER	<.200E+00	.100E+01	.000E+00	.000E+00	.000E+00
SODIUM	>.230E+03	>.244E+03	.600E+02	U.000E+00	.000E+00
STRONTIUM	.200E+03	.390E+03	.900E+00	.200E-02	.000E+00
SULFUR	.110E+05	>.600E+03	.200E+02	.130E+05	.000E+00
TANTALUM	.300E+00	.800E+00	.000E+00	.000E+00	N.000E+00
TELLURIUM	.300E+00	.000E+00	.000E+00	<.100E-02	N.000E+00
TERBIUM	.200E+01	.100E+01	.000E+00	.000E+00	N.000E+00
THALLIUM	.100E+02	.100E+02	.000E+00	.000E+00	N.000E+00
THORIUM	.170E+02	.180E+02	<.300E+00	.000E+00	.000E+00
THULIUM	.300E+00	.800E+00	.000E+00	.000E+00	N.000E+00
TIN	.600E+00	.400E+01	.000E+00	.400E-02	N.000E+00
TITANIUM	>.100E+04	>.100E+04	.100E+00	.470E-01	.000E+00
TUNGSTEN	.200E+01	.500E+01	.000E+00	.000E+00	N.000E+00
URANIUM	.800E+02	.680E+02	<.200E+00	.000E+00	.000E+00
VANADIUM	.460E+03	.480E+03	.000E+00	.800E-02	.000E+00
YTTERBIUM	.200E+01	.600E+01	.000E+00	.000E+00	N.000E+00
YTTRIUM	.300E+02	.140E+03	.000E+00	<.100E-02	N.000E+00
ZINC	.150E+03	.160E+03	.000E+00	>.993E+01	.000E+00
ZIRCONIUM	.150E+03	.619E+02	.400E+00	.500E-02	.000E+00

PPM		ADELPHI COAL-OIL-WATER PPM
ELEMENT	FUEL-COW	
ALUMINUM	>.200E+02	
ANTIMONY	.000E+00	
ARSENIC	.400E+01	
BARIUM	.220E+02	
BERYLLIUM	.300E+00	
BISMUTH	.000E+00	
BORON	.200E+01	
BROMINE	.700E+00	
CADMIUM	.400E-01	
CALCIUM	>.100E+03	
CERIUM	.100E+01	
CESIUM	.300E+00	
CHLORINE	.100E+01	
CHROMIUM	.600E+01	
COBALT	.200E+01	
COPPER	.300E+01	
DYSPROSIUM	.000E+00	
ERBIUM	.000E+00	
EUROPIUM	500E-01	
FLUORINE	.700E+01	
GADOLINIUM	.000E+00	
GALLIUM	.100E+01	
GERMANIUM	.600E+00	
HAFNIUM	.000E+00	
HOLMIUM	.000E+00	
IODINE	.400E+00	
IRON	>.100E+03	
LANTHANUM	.200E+01	
LEAD	.400E+01	
LITHIUM	.100E+01	
LUTETIUM	.000E+00	
MAGNESIUM	.920E+02	
MANGANESE	.100E+02	
MERCURY	.000E+00	
MOLYBDENUM	.100E+01	
NEODYMIUM	.600E+00	
NICKEL	.800E+01	
NIOBIUM	.500E+00	
PHOSPHORUS	.350E+02	
PLATINUM	.000E+00	
POTASSIUM	>.100E+03	
PRASEODYMIUM	.300E+00	
RUBIDIUM	.200E+01	
SAMARIUM	.400E+00	
SCANDIUM	.300E+00	

PPM		ADELPHI COAL-OIL-WATER PPM
ELEMENT	FUEL-COW	
SELENIUM	.300E+01	
SILICON	>.100E+03	
SILVER	.800E-01	
SODIUM	>.510E+02	
STRONTIUM	.800E+01	
SULFUR	.160E+05	
TANTALUM	.000E+00	
TELLURIUM	.000E+00	
TERBIUM	.000E+00	
THALLIUM	400E+00	
THORIUM	400E+00	
THULIUM	.000E+00	
TIN	.500E-01	
TITANIUM	>.100E+03	
TUNGSTEN	.000E+00	
URANIUM	.700E+00	
VANADIUM	.150E+02	
YTTERBIUM	.000E+00	
YTTRIUM	.300E+01	
ZINC	.600E+01	
ZIRCONIUM	.600E+00	

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA-600/7-84-095a	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Environmental Assessment of a Firetube Boiler Firing Coal/Oil/Water Mixtures; Volume I. Technical Results		5. REPORT DATE September 1984 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R. DeRosier		8. PERFORMING ORGANIZATION REPORT NO. TR-81-89/EE
9. PERFORMING ORGANIZATION NAME AND ADDRESS Acurex Corporation Energy and Environmental Division P.O. Box 7555 Mountain View, California 94039		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-02-3188
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; 2/81 - 11/83 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Robert E. Hall, Mail Drop 65, 919/541-2477. Volume II is a Data Supplement.

16. ABSTRACT This volume describes emission results from sampling of flue gas from a firetube boiler burning a coal/oil/water (COW) mixture and COW with soda ash added (COW+SA) to control SO2 emissions. Measurements included: continuous monitoring of flue gas emissions; source assessment sampling system (SASS) sampling of the flue gas with subsequent laboratory analysis of the samples to give total flue gas organics in two boiling point ranges, specific quantitation of the semivolatile organic priority pollutant species, and flue gas concentrations of 73 trace elements; Method 5 sampling for total particulate; and controlled condensation system sampling for SO2 and SO3 emissions. Flue gas SO2 emissions decreased almost 99% with soda ash addition from 1,089 to 13.6 ppm (3% O2). NOx emissions decreased slightly from 477 to 427 ppm, while CO emissions increased significantly from an average of 25 to 426 ppm (all at 3% O2). Particulate loading at the boiler outlet almost doubled (from 1,970 to 3,715 pg/dscm) with the additive. The size distribution of particulate also shifted to a much smaller mean diameter. Total organic emissions increased from 6.7 to 13.1 mg/dscm; most of the increase were nonvolatile (C16+) organics. Of the semivolatile organic priority pollutant species, only fluoranthene and phenanthrene were detected with the COW fuel, and phenanthrene with the COW+SA fuel.

17. KEY WORDS AND DOCUMENT ANALYSIS			
a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Assessments	Pollution Control	13B 14B
Fire Tube Boilers		Stationary Sources	13A
Coal	Flue Gases	Coal/Oil/Water Mixture	21D 21B
Fuel Oil		Environmental Assessment	
Water			07B
Sodium Carbonates			

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
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